Aviation Research
Education
Training

Accomplishments Report
FY 1997- 2004

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2004

INTRODUCTION

AIR TRANSPORTATION CENTERS OF EXCELLENCE (COE)

enable the Federal Aviation Administration (FAA) to enhance internal research capabilities and access academia and industry resources while striving to hasten the application of research to benefit the aviation community and the flying public. Through long-term collaborative efforts, the government and these affiliates effectively link to build competence and to leverage resources by sharing facilities and expertise.

By establishing a network of prestigious aviation research centers throughout the country to advance mission-critical technologies, the FAA is able to create a talent pool of scientists and engineers trained in aviation research. The agency actively supports aviation-related graduate education; fosters strategic government/academia/industry-focused research and development (R&D); and improves the national airspace system by transferring technology and new knowledge.

Centers are established on behalf of the FAA Administrator, following a highly competitive and rigorous review by senior management officials and scientists. The federal government makes a commitment to fund centers over a period of three to ten years. Thereafter, each is expected to be a self-supporting national resource. As partners, the government and academia share equally in operating the Center and in funding basic research costs.

These strategic research partnerships are initially established via cooperative agreements and funded by continuing grant awards. Approval gained in 1995 through the White House Reinvention Laboratory provides for single-source contract awards to Centers, making them more responsive to aviation needs. This combination of grant and sole-source contracts ensures that successful research can move to engineering development and rapid prototyping as required and deliverables are obtainable without delay.

Centers now form a cumulative repository of knowledge and perform the entire spectrum of aviation research. It is expected that the national network of these Centers of Excellence will be a major contributor to the FAA's commitment to reduce future air transportation risks and to maintain the safest aviation system in the world.

This Preliminary Accomplishments Report reflects Air Transportation Centers of Excellence research, education, training, and information dissemination activities from August 1997 through August 2002. *For further information, contact Patricia Watts, FAA Centers of Excellence Program Director, telephone (609) 485-5043, email:* patricia.watts@faa.gov.

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Airport Technology

Established April 1995

The University of Illinois at Urbana-Champaign

with support from Northwestern University, Embry-Riddle Aeronautical University, and North Carolina Agricultural and Technical State University

The FAA Center of Excellence for Airport Technology, located at the University of Illinois at Urbana-Champaign (UIUC) with affiliates at Northwestern University, Chicago, IL, and Embry-Riddle University, Prescott, AZ, and North Carolina Agricultural and Technical State University, Greensboro, NC, has a strong working partnership with the Federal Aviation Administration. The Center's initial focus on advances in airport pavement research has been continued and expanded to include research into airport wildlife hazard mitigation. In the area of airport pavements, the Center has continued to support the FAA's National Airport Pavement Test Facility located at the William J. Hughes Technical Center. This is an extremely important program that will have both national and international impact on future commercial aviation activities. In addition, several new research projects will benefit the FAA as it develops new advanced pavement design procedures for next generation aircraft. The assembled research team is experienced in conducting basic research in airport pavement technology, including modeling of airport pavement structures, constitutive behavior of pavement materials, material characterizations, and advancement in the art of pavement evaluation.

In the area of wildlife strike mitigation, the Center has also established a team of experts to conduct research in wildlife habitat management, wildlife ecology, Geographic Information Systems, radar applications, and statistics.

Considerable progress is being made in the COE research programs, as evidenced by the publication of over 300 technical papers and reports derived from the research studies. Papers have been presented at national conferences and meetings, including the FAA Worldwide Airport Technology Transfer Conferences in 1999 and 2002, ASCE Airfield Pavement Conferences in Seattle (1997) and Chicago (2001), and Transportation Research Board Annual Meetings in Washington, DC. Other papers have been published in the ASCE *Journal of Engineering Mechanics,* and the ASCE *Journal of Transportation Engineering*, and in such diversified publications as the Proceedings for the SPIE Conference on Aging Aircraft and Airports and the *Journal of the Acoustical Society of America*.

Sponsor: Airport & Aircraft Safety R&D Division
FAA COE PM: Dr. David R. Brill (609-485-5198)
Faculty: 20

Technical Director (217-893-0004)
Ernest J. Barenberg, Associate Director (217-333-6252)
Marshall R. Thompson, Associate Director (217-333-3930)

Students: 20

Current Projects: 11
Publications to date: 267, 18 Ph.D. theses, and 19 COE technical reports.

Projects:

Analysis of Pavement Response Data from Denver International Airport
Investigators: E.J. Barenberg and J.R. Roesler
Research Assistant: D. Rufino

The objective of this research effort is to investigate changes in pavement responses at the Denver International airport (DIA) over time and/or traffic. Factors that are likely to lead to changes in pavement responses are loading conditions, climatic effects, and moisture effects. The focus in this study is on analyzing pavement responses over time for similar loading conditions; analyzing the effects over time due to changing temperature and moisture content; and analyzing results from sensors in the pavement due slab loading with FWD/HWD equipment and aircraft of known weights. Finite element models (2-D and 3-D) and Integrated Climatic Models and statistical methods are used to evaluate the results.

Analyses of NAPTF Pavement Response Data
Investigators: M.R. Thompson, E.J. Barenberg, and B.J. Dempsey
Post-Doctoral Research Assistant: F. Gomez-Ramirez

Flexible and rigid pavement test sections have been constructed in the National Airport Pavement Test Facility (NAPTF) at the FAA William J. Hughes Technical Center. Extensive instrumentation has been installed in the pavement test sections. Data on material and soil properties and as constructed conditions (density/moisture/strength properties) are available and additional soils/materials testing has been conducted as part of a FAA/University of Illinois COE project.

Materials Testing and Evaluation for NAPTF
Investigators: S.H. Carpenter and E. Tutomluer
Research Assistant: U. Seyhan

The overall objective in the project is to provide supporting information on material properties to characterize engineering behavior of different pavement layers. Efforts focus on sampling materials from the pits opened up in support of forensic evaluation of the trafficked sections (in the wheel tracks and at the centerline); collecting and analyzing data from in-place CBR, DCP, and moisture density tests to be conducted at the pit locations opened; developing a laboratory permanent deformation test procedure that is more representative of airport loading conditions, one that can apply on P209 and P154 aggregates and the asphalt concrete, the significantly high stresses produced in the granular layers under up to 65,000 lb wheel loads; and conducting laboratory strength, permanent deformation, and modulus tests on the pavement foundation materials, and the three different subgrades.

Fatigue Resistance of Airport Concrete Pavements
Investigator: J.R. Roesler
Research Assistant: P. Littleton

The main objective of this project is to determine how to count fatigue cycles for a single tridem gear pass. Four major areas are to be addressed are the effects of different load pulses and slab thickness on the fatigue behavior of concrete, the effect of initial moisture and temperature curling strains in the concrete slab prior to loading, and a compilation of airfield concrete pavement fatigue from the 1940's to the present.

Analysis of Flexible Overlay Systems for Airport Pavements
Investigator: W.G. Buttlar
Research Assistant: D. Bozkurt

In light of the exponentially-increasing computational power, there is a critical need to evaluate the current design assumptions and procedures tin the FAA overlay design method using modern analysis tools, fundamental material tests, and instrumented field demonstration projects. This project is focused on the analysis of flexible overlays placed on either flexible or rigid bases. The analysis will also permit the modeling of interlayer fabrics, grids, and base-isolating mixtures.

Model to Predict Fatigue Response of Concrete Airport Pavement
Investigator: S.P. Shah

The main objective of this study is to understand the response of concrete subjected to high amplitude low cycle biaxial fatigue loading in the C-T stress space. Characterization of the material response under quasi-static loading and establishment of the mechanism of failure under such loading is an essential first step in the process. A predictive model for response of concrete under fatigue loading will be established.

Modification of Coal-Tar Rejuvenator Specification
Investigator: S.H. Carpenter

Bituminous surface seals are commonly used on asphalt airport pavements in order to prolong the life of the pavement and to reduce or defer the need for more costly rehabilitation. Materials known as coal-tar sealer/rejuvenators combine coal-tar and coal-tar oils with an petroleum-based rejuvenating agent. This project is designed to identify possible areas of improvement for existing FAA coal-tar sealer/rejuvenator specifications and propose performance standards for coal-tar rejuvenator/sealers and similar products that may be adopted by the FAA.

Graduate Minority Summer Internship Program
Investigator: F.C. Coleman III and B.J. Dempsey

As part of the activities of the COE, a Summer Internship Program has been initiated. The objective of the program will be to increase the number of under-represented minorities obtaining advanced degrees relevant to improving airfield pavement technology.

Development of a Wildlife Hazard Information Prototype for WHAS
Investigator: Edwin Herricks

The COE has developed a research approach based on an understanding of FAA needs and

requirements and an awareness of advanced techniques in wildlife management, risk assessment, monitoring, and computer systems. This approach recognizes the major role the FAA plays in supporting all aspects of airport operations and aircraft movement. Although each airport may present a singular set of issues to challenge wildlife hazard abatement, there are sufficient similarities associated with airport/aircraft operation, wildlife behavior, and abatement technologies to encourage a systematic approach to wildlife hazard abatement. This suggests that a WHAS, developed to provide a systematic approach, is a critical component of future airport safety technology. As a part of continuing development of WHAS components, this research will advance the Wildlife Hazard Information component of WHAS, a GIS-based consolidation of wildlife and airport operations information.

Review and Assessment of Radar/Sensor Application in WHAS
Investigator: Edwin Herricks

A critical need in WHAS development is the identification of wildlife sensing and warning technologies that can be used in the airport setting (approximately 6 miles from the airport to an altitude of 3000 ft agl). This project evaluates and prioritizes FAA/WHAS radar/sensor requirements for avoiding collisions of civilian aircraft with birds in the airport vicinity. In addition, this project identifies existing radar installations, radar systems, and other sensors potentially useful in meeting radar/sensor requirements for avoiding collisions of civilian aircraft with wildlife in the airport vicinity.

Development of WHAS Support for Evaluation of Radar Detection/Recognition of Wildlife Hazards at DFW Airport
Investigator: Edwin Herricks

This research is conducted in support of a continuing FAA program of research and development directed to airport safety technologies that will decrease aircraft damage and the risk of human fatalities or injuries by reducing bird and wildlife strikes near airports. The longer term gails of that research area include the development of FAA Wildlife Hazard Abatement System (WHAS) elements for airports and national aircraft movement that is specific to FAA needs for civilian aircraft. The WHAS is envisioned as a real-time, or near real-time, warning system, which is risked-based, and is applicable to the site-specific needs of airports as well as the needs of civilian aircraft transiting large areas where wildlife hazards must be abated

Publications:

FAA COE Ph.D. Theses:

Abdel-Maksoud, M.G., "Relationship Between Joint Performance and Geometrical and Mechanical Properties of Concrete Joints Subject to Cyclic Shear," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1999.

Altoubat, S.A., "Early Age Stresses and Creep-Shrinkage Interaction of Restrained Concrete," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1999.

Bejarano, M.O., "Subgrade Soil Evaluation for the Design of Airport Flexible Pavements, " Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1999.

Eom. I.-S., "Nonlinear Analysis of the Load Transfer Mechanisms in Rigid Airport Pavement Systems Considering Various Interface Conditions," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1999.

Habboub, A.K., "Evaluation/Characterization of Airport Pavements Using the Impact-Echo and Spectral Analysis of Surface Waves," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 2000.

Hongschaovalit, P., "Development and Evaluation of a Modified VFR Lighted Flyway Marker, " Ph.D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, 2000.

Kim, J., "Three-Dimensional Finite Element Analysis of Multi-Layered Systems: Comprehensive Nonlinear Analysis of Rigid Airport Pavement Systems," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1999.

Roesler, J.R., "Fatigue of Concrete Beams and Slabs," Ph.D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, February 1998.

Shin, H.-C., "Early Age Behavior of Bonded Concrete Overlays Due to Shrinkage and Thermal Changes," Ph.D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, 2000.

Signore, J.M., "Accelerated Testing of Separation Layers for Open-Graded Drainage Layers," Project C960014, Ph.D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, August 1998.

Song, W.-J., "Nondestructive Evaluation Techniques Using Impact Generated Stress Waves in Concrete," Ph.D. Thesis, Northwestern University, December 2000.

Subramanian, K., "Fatigue of Concrete Subjected to Biaxial Loading in the Tensile Region,"

Ph.D. Thesis, Northwestern University, 1999.

Taciroglu, E., "Constitutive Modeling of the Resilient Response of Granular Solids," Ph.D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign, August 1998.

Vavrik, W.R., "Asphalt Mixture Design Concepts to Develop Aggregate Interlock," Ph.D. Thesis, University of Illinois at Urbana-Champaign, July 2000.

Wattar, S.W., "Aggregate Interlock Behavior of Large Crack Width Concrete Joints in PCC Airport Pavements," Ph.D. Thesis, University of Illinois at Urbana-Champaign, May 2001.

Zhou, C., "Point Load Excitation of a Multi-Layered Structure: Ray Theory and Experimental Verification," Ph.D. Thesis, Northwestern University, 1999.

FAA COE Technical Reports and Publications:

Abdel-Maksoud, M.G., N.M. Hawkins, and E.J. Barenberg, "Effect of Geometric and Mechanical Properties of Concrete Joints on Their Cyclic Shear Response," presented at The Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey on April 11-16, 1999.

Abdel-Maksoud, M.G., N.M. Havvkins, and E.J. Barenberg, "Behavior of Concrete Joints Under Cyclic Shear, Aircraft Pavement Technology in the Midst of Change," *American Society of Civil Engineers*, New York, NY, Frank V. Herman, ed., August 1997, p. 190-204.

Altoubat, S.A. and D.A. Lange, "Early Age Shrinkage and Creep of Fiber Reinforced Concrete of Airfield Pavement," published in Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington, August 17-20, 1997, pp. 229-243.

Altoubat, S.A. and D.A. Lange, "A New Look at Tensile Creep of Fiber Reinforced Concrete," submitted for ACI Special Publication on Fiber Reinforced Concrete, N. Banthia, ed., 2001.

Altonbat, S.A. and D.A. Lange, "Creep, Shrinkage, and Cracking of Early Age Concrete," *ACI Materials Journal*, 2000.

Altoubat, S.A. and D.A. Lange, "Tensile Basic Creep: Measurements and Behavior at Early Age," *ACI Materials Journal*, 2001.

Altoubat, S.A. and D.A. Lange, "The Pickett Effect at Early Age and Experiment Separating its Mechanisms in Tension," *Materials and Structures*, 2000.

Altoubat, S.A. and D.A. Lange, "The Pickett Effect in Early Age Concrete Under Restrained Conditions," in proceedings of RILEM International Conference on Early Age Cracking in Cementitious Systems (EAC-01), pp. 133-44, Haifa, Israel, March 12-14, 2000.

Arellano, D. and M.R. Thompson, "Stabilized Base Properties (Strength, Modulus, and Fatigue) for Mechanistic-Based Airport Pavement Design, Final Report," COE Report No. 4, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 1998.
Barenberg, E.J. and N.M. Hawkins, "Implications of Aggregates on Load Transfer Efficiency for Airport Pavements," FAA Regional Conference, Chicago, IL, November 1999.

Bejarano, M. and M.R. Thompson, "Characterization of NAPTF Subgrades," presented (and included on Conference CDROM Proceedings) at the 1999 FAA Technology Transfer Conference, Atlantic City, NJ, April 1999.

Bejarano, M. and M.R. Thompson, "Subgrade Damage Approach for Design of Airport Flexible Pavements," Proceedings of the 2001 Airfield Pavement Specialty Conference, 27th ASCE International Air Transportation Conference, Chicago, Illinois, August 2001.

Bejarano, M. and M.R. Thompson, "Subgrade Soil Evaluation for the Design of Airport Flexible Pavements," COE Report No. 8, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, June 1999.

Buttlar, W.G., D. Bozkurt, M.R. Thompson, and S.M. Smith, "The Rantoul Demonstration Project: Techniques for Reflective Crack Mitigation at GA Airports," Proceedings, 2001 Airfield Specialty Conference, 27th ASCE International Air Transportation Conference, Chicago, Illinois, August 2001.

Buttlar, W.G. and S.M. Smith, "Innovative Methods for Cost-Effective Rehabilitation of General Aviation Airfields," Proceedings, Fifteenth Annual Airport Conference, Federal Aviation Administration, Great Lakes Region, Chicago, IL, November 1999.

Buttlar, W.G. and S.M. Smith, "Rehabilitation Alternatives for Runway 18-36 at Rantoul: Phase 1 - Report on Site Investigation, Preliminary Testing, Instrumentation Plan, and Construction Sampling Plan," Illinois Division of Aeronautics, Illinois Department of Transportation, Springfield, IL, July 1999.

Buttlar, W.G. and S.M. Smith, "Rehabilitation Alternatives for Runway 18-36 at Rantoul: Phase 2 - Report on Construction, Materials Testing, Field Instrumentation, and Post-Construction Distress Survey," Illinois Division of Aeronautics, Illinois Department of Transportation, Springfield, IL, July 2000.

Carpenter, S.H. and T.W. Glade, "Performance Evaluation of Laboratory Segregated Asphalt Mixes for Airport Pavements," presented at The Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, on April 11-16, 1999.

Carpenter, S.H. and M. Jansen, "Fatigue Behavior Under New Aircraft Loading Conditions," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington, April 17-20, 1997.

Ceylan, EL, E. Tutumluer, and E.J. Barenberg, "Artificial Neural Networks as Design Tools in Concrete Airfield Pavement Design," Proceedings, 25th International Air Transportation Conference, Austin, Texas, June 14-17, 1998, pp. 447-465.

Ceylan, H., E. Tutumluer, and E.J. Barenberg. Artificial Neural Network Analysis of Concrete Airfield Pavements Serving the Boeing B-777 Aircraft, Proceedings, 78th Annual Meeting of the Transportation Research Board, National Research Council, Washington, DC, January 1999.

Ceylan, H., E. Tutumluer, and E.J. Barenberg, "Artificial Neural Network Modeling of Concrete Airfield Pavements," Proceedings, 13th ASCE Engineering Mechanics Conference, John Hopkins University, Baltimore, MD, June 13-16, 1999.

Ceylan, H., E. Tutumluer, and E.J. Barenberg, "Effects of Combined Temperature and Gear Loading on the Response of Concrete Airfield Pavements Serving the Boeing B-777 Aircraft, In 2020 Vision of Air Transportation - Emerging Issues and Innovative Solutions," edited by S.S. Nambisan, Proceedings, 26th International Air Transportation Conference (IATC), San Francisco, California, June 18-21, 2000, pp. 25-44.

Ceylan, H., E. Tutumluer, and E.J. Barenberg, "Neural Network Modeling of Slabs Under Simultaneous Aircraft and Temperature Loading," Proceedings, 14th ASCE Engineering Mechanics Conference, EM2000, The University of Texas, Austin, Texas, May 21-24, 2000.

Ceylan, H., E. Tutumluer, and E.J. Barenberg, "Effects of Simultaneous Temperature and Gear Loading on the Response of Concrete Airfield Pavements Serving the Boeing B-777 Aircraft," Proceedings, ASCE 26th International Air Transportation Conference, San Francisco, California, June 18-21, 2000.

Coleman, F. Ill, R.F. Benekohal, and E. Shrum, "Technology Transfer Activities and Models - Survey Findings from Technology Transfer Agencies, Final Report," COE Report No. 3, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 1998.

Crane, N., K.J. Hjelmstad, and I.D. Parsons, "Analysis of the Validity of LTE(delta) in Characterizing the Efficiency of Airport Pavement Joints," In preparation.

D-Ambrosia, M.D., S.A. Altoubat, C. Park, and D.A. Lange, "Early Age Tensile Creep and Shrinkage of Concrete with Shrinkage Reducing Admixtures," Proceedings, CONCREEP-01, Boston, Massachusetts, August 13-15, 2001.

Dempsey, B.J. and M.T. Mukhtar, "Interlayer Stress Absorbing Composite (ISAC) in AC Overlays," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington. April 17-20, 1997.

Eom, I.-S., "Nonlinear Analysis of the Load Transfer Mechanism in Rigid Pavement Systems Considering Various Interface Conditions," COE Report No. 9, Department of Civil

Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, 1999.

Eom, I.-S. and I.D. Parsons, "A Finite Element Study of Load Transfer Between Doweled Pavement Slabs," Submitted to the Transportation Research Board for the 1997 Annual Meeting.

Eom, I.-S., I.D. Parsons, and K.D. Hjelmstad, "A Finite Element Study of Load Transfer Between Doweled Pavement Slabs," Proceedings, 4th International Workshop on Design Theories and Their Verification of Concrete Slabs for Pavements and Railroads, September 10-11, Bussaco, Portugal, 1998.

Garg, N., E. Tutumluer, and M.R. Thompson, "Structural Modeling Concepts for the Design of Airport Pavements for Heavy Aircraft." Proceedings, Fifth International Conference on the Bearing Capacity of Roads and Airfields, Trondheim, Norway, July 1998, pp. 115-124.

Glade. T. and S.H. Carpenter, "Performance Evaluation of Laboratory Segregated Asphalt Mixes." at the 1999 Federal Aviation Administration Technology Transfer Conference, Atlantic City, April 1999.

Ghuzlan, K. and S.H. Carpenter, "A Dissipated Energy/Damage Accumulation Approach for Defining Failure in Flexural Fatigue Testing," at the Transportation Research Board annual meeting, January 2000.

Ghuzlan, K. and S.H. Carpenter, "Rate of Dissipated Energy as the Unifying Element in Fatigue," at the 1999 Transportation Research Board annual meeting, 1999.

Gomez-Ramirez, F.M. and M.R. Thompson, "Aircraft Multiple Wheel Gear Load Interaction Effects on Airport Flexible Pavement Responses," Proceedings of the 2001 Airfield Pavement Specialty Conference, 27th ASCE International Air Transportation Conference, Chicago, Illinois, August 2001.

Haussinann, L.D., E. Tutumluer, and E.J. Barenberg, :Neural Network Algorithms for the Correction of Concrete Slab Stresses from Linear Elastic Layered Programs," Transportation Research Record 1568. Transportation Research Board, Washington, DC, 1997, pp. 44-51.

Hawkins, N.M., E.J. Barenberg, and S.W. Wattar, "Precast Replacement Slabs for Airport Pavements," Proceedings, PCI Convention, New Orleans, LA, October 1997.

Hjelmstad, K.D., J. Kim, and Q. Zuo, "Finite Element Procedures for Three Dimensional Pavement Analysis," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington, pp. 125-137.

Hjelmstad, K.D., I.D. Parsons, Q. Zuo, I.-S. Eom, J. Kim, and E. Taciroglu, "State-of-the-Art Equation Solvers for Finite Element Models of Three Dimensional Pavements," Proceedings, 1997 ASCE Airfield Pavement Conference, Seattle, Washington.

Hjelmstad, K.D., and E. Taciroglu, "A Consistent Finite Element Implementation of the K-Theta

and Uzan-Witczak Models," *ASCE J. Engrg. Mechanics*, 1999.

Hjelmstad, K.D. and E. Taciroglu, "A Coupled Hyperelastic Constitutive Model for Resilient Response of Granular Materials," Proceedings, Aircraft/Pavement Technology: In the Midst of Change. 1997 ASCE Airfield Pavement Conference, Seattle, Washington, pp. 178-189.

Hjelmstad, K.D. and E. Taciroglu, "Analysis and Implementation of Resilient Modulus Models for Granular Solids," *Journal of Engineering Mechanics*, August 2000, pp. 821-830.

Hjelmstad, K.D. and E. Taciroglu, "Modeling the Resilient Response of Asphalt Pavements," Proceedings, 12th Engineering Mechanics Conference, ASCE, May 17-20, LaJolla, California, 1998.

Hjelmstad, K.D., Q. Zuo, and J. Kim, "Elastic Pavement Analysis Using Infinite Elements," Transportation Research Record 1568, pp. 72-76.

Kapiri, M., E. Tutumluer, and E.J. Barenberg, "Analysis of Temperature Effects on Pavement Response at Denver International Airport, In 2020 Vision of Air Transportation - Emerging Issues and Innovative Solutions," S.S. Nambisan, ed., Proceedings, 26th International Air Transportation Conference (IATC), San Francisco, California, June 18-21, 2000, pp. 125-143.

Kim, J. and W.G. Buttlar, "Analysis of Reflective Crack Control System Involving Reinforcing Grid Over Base-Isolating Interlayer Mixture," *Journal of Transportation Engineering*, American Society of Civil Engineers, 2000.

Kim, J. and K.D. Hjelmstad, "Response of Rigid Airport Pavements Under Temperature Differential," presented at the Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 1999.

Kim, J. and K.D. Hjelmstad, "Rigid Airport Pavement Study Under Temperature Differential and Thickness Variation," the Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 1999.

Kim, J. and K.D. Hjelmstad, "Three-Dimensional Finite Element Analysis of Multi-Layered Systems: Comprehensive Nonlinear Analysis of Rigid Airport Pavement Systems," COE Report No. 10, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, January 2000.

Kim, J. and K.D. Hjelmstad, "Three-Dimensional Finite Element Analysis of Rigid Airport Pavement Systems I: Issues in Numerical Modeling," In preparation.

Kim, J. and K.D. Hjelmstad, "Three-Dimensional Finite Element Analysis of Rigid Airport Pavement Systems II: Results of Numerical Modeling," In preparation.

Kim, J., Q. Zuo, and K.D. Hjelmstad, "Three Dimensional Finite Element Study of Wheel-Load Interaction," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE

Airfield Pavement Conference, Seattle, Washington, pp. 138-150.

Lange, D.A. and S.A. Altoubat, "Early Age Creep-Shrinkage Interaction of Cement-Based Matrices," Proceedings of the 5th International Symposium on Brittle Matrix Composites (BMC-6), A. Brandt, ed., Warsaw, Poland, October 9-11, 2000.

Lange, D.A. and S.A. Altoubat, "Early Age Shrinkage and Creep of Fiber Reinforced Concrete," Proceedings, 1997 International Conference on Engineering Materials, Al-Manaseer, et al., ed., Ottawa, June 8-11, 1997, pp. 343-355.

Lange, D., N. Rau, B. Bicer, and H.-C. Shin, "Early Age Cracking of Concrete Bonded Overlays for Airport Pavements," Interim Report, Illinois Department of Transportation, January 1999.

Lange, D., L.J. Struble, F. Young, S. Altoubat, and H. Ai, "Early Age Shrinkage and Creep of High Performance Concrete," PCI/FHWA International Symposium on High Performance Concrete, pp. 118-123, October 1997.

Larson, G. and B.J. Dempsey, "Enhanced Integrated Climatic Model, Final Report," DTFA Mn-DOT 72114, October 1997.

Parsons, I.D, "Adaptive Multigrid Methods for Finite Element Models of Three Dimensional Pavements," presented at the Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 1999.

Parsons, LD, "Application of Meshless Ritz Method to Rigid Pavement Systems," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington, April 17-20, 1997.

Parsons, I.D., I.-S. Eom, and K.D. Hjelmstad, "Numerical Simulations of Load Transfer Between Doweled Pavement Slabs," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, F. V. Hermann, ed., 1997 ASCE Airfield Pavement Conference, Seattle, Washington, August 17-20, 1997, pp. 166-177.

Popovics, J.S., "Comments on Determination of Elastic Constants of a Concrete Specimen Using Transient Elastic Waves," *Journal of the Acoustical Society of America*, Vol. 100, No. 5, 1996, pp. 3451-3453.

Popovics, J.S, "Effects of Poisson's Ratio on Impact-Echo Analysis," *ASCE Journal of Engineering Mechanics*, Vol. 123, No. 8, 1997, pp. 843-851.

Popovics, J.S., "Ultrasound and Sound Generation Alternatives for Concrete Structures," Proceedings, 2nd International Conference on Nondestructive Testing of Concrete in the Infrastructure, Society for Experimental Mechanics, 1996, pp. 108-117.

Popovics, J.S. and J.D. Achenbach, "Airport Pavement NDE Research at CQEFP in Nondestructive Evaluation Techniques for Aging Aircraft, Airports, and Aerospace Hardware,"

R.D. Rempt and A.L. Broz, eds., Proceedings of SPIE, Vol. 2945, 1996, pp. 294-302.

Popovics, J.S., J.D. Achenbach, and W. Song, "Application of New Ultrasound and Sound Generation Methods for Testing Concrete Structures" *Magazine of Concrete Research*, 1999, 51, No. 1, February, 1999, pp. 35-44.

Popovics, J.S., W. Song, K.V. Subramaniam, J.D. Achenbach, and S.P. Shah, "Crack Depth Determination in Concrete Slabs Using Wave Attenuation Measurements," presented at the Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, on April, 1999.

Popovics. J.S. and K.V. Subramaniam, "Discussion of Free Vibration of Thick Hollow Circular Cylinders from Three-Dimensional Analysis," *ASME Journal of Vibration and Acoustics*.

Popovics, J.S., K.V. Subramaniam, and S.P. Shah, "Vibrational Resonances in Finite Length Concrete Cylinders," *ASNT Nondestructive Testing and Evaluation for the Aging Infrastructure Special Topics Volume.*

Popovics. J.S., W. Song, and J.D. Achenbach, "A Study of Surface Wave Attenuation Measurement for Application to Pavement Characterization in Structural Materials Technology III: An NDT Conference," R.D. Medlock and D.C. Laffey, eds., Proceedings of SPIE, Vol. 3400, 1998, pp.300-308.

Popovics, J.S., W. Song., J.D. Achenbach, J.H. Lee, and R.F. Andre, "One-Sided Stress Wave Velocity Measurement in Concrete," *ASCE Journal of Engineering Mechanics*.

Popovics, J.S., W. Song, K.V. Subramaniam, J.D. Achenbach, S.P. Shah, and R.F. Andre. "Concrete Pavement Characterization Using Surface Wave Velocity and Attenuation Measurements," presented at the 1997 ACI Fall Conference.

Popovics, J.S., W. Song, M. Ghandehari, K.V. Subramaniam, J.D. Achenbach, and S.P. Shah, "Application of Wave Transmission Measurements for Crack Depth Determination in Concrete," *ACI Materials Journal*.

Reis, H.L.M. dos, M.D. Barright, and A.K. Habboub, "Nondestructive Evaluation of Ground Support in Airport Pavements," Topics in Nondestructive Evaluation Series — NDT&E of Infrastructure, Vol. 2, *ASNT*, 1998, pp. 171-186.

Reis, H.L.M. dos, S.H. Carpenter, M.D. Barright, A.K. Habboub, and A.C. Voegle, "Nondestructive Evaluation of Segregation in Bituminous Pavements Using Acousto-Ultrasonics," Topics in Nondestructive Evaluation Series --NDT&E of Infrastructure, Vol. 2, ASNT, 1998, pp. 159-170.

Reis, H.L.M. dos, S.H. Carpenter, and A.K. Habboub, "Nondestructive Evaluation/Characterization ofViscoelastic Material Properties of Asphalt Concrete," Proceedings, 1999 Federal Aviation Administration Airport Technology Transfer Conference,Atlantic City, New Jersey, April 1999..

Reis, H.L.M. dos, and A.K. Habboub, "Evaluation/Characterization of Airport Pavements Using the Impact-Echo and Spectral Analysis of Surface Waves," COE Report No. 12, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, January 2000.

Reis, H.L.M. dos, and A.K. Habboub, "Nondestructive Evaluation/Characterization of Dimension Stone Using a Stress-Wave Energy Approach," abstract accepted for presentation at the "ASTM Symposium on Dimension Stone Cladding: Design, Construction, Evaluation, and Repair" sponsored by the ASTM Committee C-13 to be held October 27, 1999, in New Orleans, Louisiana. Paper in preparation to be submitted for review for ASTM Special Technical Publication (STP), 1999.

Reis, H.L.M. dos, and A.K. Habboub, "Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 1 - Theoretical Aspects and Experimental Prospects," submitted for review for publication in "Dimension Stone Cladding: Design, Construction, Evaluation, and Repair," ASTM 1394, K. R. Hoigard, ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Reis, H.L.M. dos, and A.K. Habboub, "Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 2 — Estimation of Complex Moduli," submitted for review for publication in "Dimension Stone Cladding: Design, Construction, Evaluation, and Repair," ASTM 1394, K..R. Hoigard. rd.. American Society for Testing and Materials, West Conshohocken, PA, 2000.

Reis, H.L.M. dos, and A.K. Habboub, "Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 3 — Microstructure Characterization," submitted for review for publication in "Dimension Stone Cladding: Design, Construction, Evaluation, and Repair," ASTM 1394, K..R. Hoigard, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Reis, H.L.M. dos, and A.K. Habboub, "Nondestructive Evaluation of Viscoelastic Properties in Asphalt Concrete Using an Energy Approach," Technical Report UILU ENG 98-3003, University of Illinois, Urbana, Illinois, 1998.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "An Energy-Based Aggregate Geometric Packing Parameter for Asphalt Concrete," *INSIGHT - Non-Destructive Testing and Condition Monitoring*, British Institute of Non-Destructive Testing, March 1999.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Estimation of Sound Abatement Characteristics of Porous Asphalt Concrete Pavements—A Simple Model," 2000 Transportation Research Board (1999).

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Noise Abatement In Asphalt Concrete Pavements: Part I — Nondestructive Estimation of Characteristic Lengths Using an Impulse-Echo Approach," submitted for review towards presentation and publication to the Transportation Research Board, 1999.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Noise Abatement In Asphalt Concrete Pavements: Part II — Estimation of Acoustic Properties," submitted for review towards presentation and publication to the Transportation Research Board, 1999.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Nondestructive Acoustic Characterization of Porous Asphalt-Concrete," to be submitted for review towards presentation at the Transportation Research Board Meeting in January 2000, and potential publication in the 2000 Transportation Research Record Series, (in preparation), 1999.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Nondestructive Evaluation of Complex Moduli in Asphalt Concrete," presented at the ASNT Spring Conference and 8th Annual Research Symposium, Orlando, Florida, March 22-26, 1999, Abstract, p. 133.

Reis, H.L.M. dos, A.K. Habboub, and S.H. Carpenter, "Nondestructive Evaluation of Complex Moduli in Asphalt Concrete Using an Energy Approach." (Preprint Number 990309) Transportation Research Board (1998), Washington, D.C., 1998. To appear in the 1999 Transportation Research Record Series.

Rufino, D. J.R. Roesler, E.J. Barenberg, and E. Tutumluer, "Analysis of Pavement Responses to Aircraft and Environmental Loading at Denver International Airport," 7th International Conference on Concrete Pavements, Orlando, Florida, September 9-13, 2001.

Rufino, D. J.R. Roesler, E. Tutumluer, and E.J. Barenberg, "Wander Patterns for Commercial Aircraft at Denver International Airport," Proceedings, 2001 Airfield Specialty Conference, 27th ASCE International Air Transportation Conference, Chicago, Illinois, August 2001.

Salinas, G.E, "Optimizing High-Performance Concrete for Processing Ultra-Thin Bonded Concrete Overlays on Airport Pavements," COE Report No. 6, Department of Civil Engineering,

University of Illinois at Urbana-Champaign, Urbana, Illinois, August 1998.

Seyhan, U. and E. Tutumluer, "Advanced Characterization of Granular Materials for Mechanistic Based Pavement Design," *Geotechnical Special Publication (GSP)* No. 98, entitled, Pavement Subgrade, Unbound Materials, and Nondestructive Testing, M.S. Mamlouk, ed. GeoDenver 2000 ASCE Geo-Institute Congress, Denver, Colorado, August 3-8, 2000, pp. 51-72.

Seyhan, U. and E. Tutumluer, "Anisotropic Behavior of Pavement Geomaterials," Proceedings. 13th ASCE Engineering Mechanics Conference, John Hopkins University, Baltimore, MD, June 1999.

Seyhan, U. and E. Tutumluer. Anisotropic Modular Ratios at Unbound Aggregate Performance Indicators, *ASCE Journal of Materials in Civil Engineering*, 2001.

Seyhan, U. and E. Tutumlner, "Characterization of Unbound Aggregates Using the New FastCell," Proceedings, 1999 Federal Aviation Administration Technology Transfer Conference, Atlantic City, NJ, April 1999.

Seyhan, U. and E. Tutumluer. "Neural Network Modeling of Anisotropic Granular Material Moduli," 12th ASCE Engineering Mechanics Conference, LaJolla, California, May 17-20, 1998.

Seyhan, U. and E. Tutumluer, "Unbound Granular Material Characterization from Stress Path Loading Tests," Recent Advances in the Characterization of Transportation Geo-Materials, *Geotechnical Special Publication* No. 89, ASCE, June 1999.

Shin, H-C. and D.A. Lange, "Early Age Behavior of Bonded Concrete Overlays Constructed on Old Concrete Pavements," Transportation Research Board Paper 01-0410, January 2001.

Shin, H-C. and D.A. Lange, "Early Age Behavior of Bonded Concrete Overlays Constructed on Old Concrete Pavements," Proceedings ACI's Fourth International Conference on Repair Innovations, Seoul, South Korea, September 19-22, 2001.

Song, W., J.S. Popovics, and J.D. Achenbach, "Crack Depth Determination in Concrete Slabs Using Wave Propagation Measurements," Proceedings, Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 1999.

Struble, L.J., R. Szecsy, and G. Salinas, "Rheology of Fresh Concrete," Proceedings, 6th International Purdue Conference on Concrete Pavement, Design, and Materials for High Performance.

Subramaniam, K.V., J.S. Popovics, and S.P. Shah, "Fatigue Behavior of Concrete Subjected to Biaxial Stresses," Proceedings, Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 11-16, 1999.

Subramaniam, K.V., J.S. Popovics, and S.P. Shah, "Fatigue Behavior of Concrete Subjected to Biaxial Stresses in the Compression-Tension Region, *ACI Materials Journal*, 1999.

Subramaniam, K.V., J.S. Popovics, and S.P. Shah, "Monitoring Fatigue Damage in Concrete in Nondestructive Characterization of Materials in Aging Systems - MRS Symposium Proceedings Series," Volume 503, R.L. Crane et al., eds., Material Research Society, Warrendale, PA, 1998, pp.151-157.

Subramaniam, K.V., J.S. Popovics, and S.P. Shah, "Testing Concrete in Torsion: Instability Analysis and Experiments," *ASCE Journal of Engineering Mechanics*.

Taciroglu, E. and K.D. Hjelmstad, "A Simple Hyperelastic Model for Resilient Response of Granular Materials," In preparation.

Taciroglu, E. and K.D. Hjelmstad, "Constitutive Modeling of the Resilient Response of Granular Solids," COE Report No. 5, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, November 1998.

Taciroglu, E. and K.D. Hjelmstad, "Eigenprojection Operators for Tension-Free Elasticity," In preparation.

Thompson, M.R. and M.O. Bejarano, "Subgrade Criteria for Airport Flexible Pavement Design," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Conference, Seattle, Washington.

Thompson, M.R. and N. Garg, "Wheel Load Interaction: Critical Airport Pavement Responses," Final Report, COE Report No. 7, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, May 1999.

Thompson, M.R., E. Tutumluer, and M. Bejarano, "Granular Material and Soil Moduli, Review of the Literature," Final Report, FAA Center of Excellence for Airport Pavement Research Report No. 1, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 1998.

Tutumluer, E. Anisotropic, "Behavior of Unbound Aggregate Bases - State-of-the-Art Summary on Anisotropic Behavior," Proceedings, 6th Annual Symposium of the International Center for Aggregate Research (ICAR), St. Louis, Missouri, April 19-21, 1998, pp. 11-33.

Tutumluer, E., "Nonlinear Anisotropic Modeling of Dilative Granular Material Behavior," Proceedings, 9th International Conference of the Association for Computer Methods and Advances in Geomechanics, IACMAG 97, Wuhan, China, November 2-7, 1997, pp. 923-928.

Tutumluer, E., H. Ceylan, and U. Seyhan, "Advanced Characterization of Granular Material Behavior Using Artificial Neural Networks,"Proceedings, XV International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Turkey, August 27-31, 2001.

Tutumluer, E., F.-J. Chou, "Characterization of Airfield Pavement Granular Layers Under Moving Wheel Loads," Proceedings, 2001 Airfield Specialty Conference, 27th ASCE

International Air Transportation Conference, Chicago, Illinois, August 2001.

Tutumluer, E., N. Garg, and U. Seyhan, "Characterization of Anisotropic Aggregate Behavior Under Variable Confinement Conditions," *Geotechnical Special Publication (GSP)* No. 85, entitled, Application of Geotechnical Principles in Pavement Engineering, ASCE Annual Convention, Boston, Massachusetts, October 1998, pp. 1-12.

Tutumluer, E., N. Garg, and M.R. Thompson, "Granular Material Radial Deformation Measurements Using a Circumferential Extensometer in Repeated Load Triaxial Testing," Transportation Research Record 1614, Transportation Research Board, National Research Council, Washington, DC, 1998, pp. 61-69.

Tutumluer, E. and U. Seyhan, "Effects of Fines Content on the Anisotropic Response and Characterization of Unbound Aggregate Bases," in Unbound Aggregates in Road Construction, A.R. Dawson, ed., A.A. Balkema Publishers, Proceedings of the Unbound Aggregates in Roads (UNBAR5) Symposium, University of Nottingham, England, June 21-23, 2000, pp. 153-160.

Tutumluer, E. and U. Seyhan, "Laboratory Determination of Anisotropic Aggregate Resilient Moduli Using the New Innovative Test Device," 78th Annual Meeting of the Transportation Research Board, Washington, DC, January 1999.

Tutumluer, E. and U. Seyhan, "Neural Network Modeling of Anisotropic Aggregate Behavior from Repeated Load Triaxial Tests," Transportation Research Record 1615, Transportation Research Board, National Research Council, Washington, DC, 1998, pp. 86-93.

Tutumluer, E. and U. Seyhan, "Stress Path Loading Effects on Granular Material Resilient Response," Proceedings, European Community COST 337 Workshop on Modeling and Advanced Testing/or Unbound Granular Materials, Institute Superior Tecnico -1ST, Lisbon, Portugal, January 21-22, 1999.

Tutumluer, E., U. Seyhan, and J. Chan, "Characterization of Granular Materials Subjected to Complex Static and Dynamic Loadings," Proceedings, 14th ASCE Engineering Mechanics Conference, EM2000, The University of Texas, Austin, Texas, May 21-24, 2000.

Tutumluer, E. and M.R. Thompson," "Anisotropic Modeling of Granular Bases, Final Report," COE Report No. 2, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 1998.

Tutumluer, E. and M.R. Thompson, "Anisotropic Modeling of Granular Bases in Flexible Pavements," Transportation Research Record 1577, Transportation Research Board, Washington, DC, 1997, pp. 18-26.

Tutumluer. E. and M.R. Thompson, "Granular Base Moduli for Mechanistic Pavement Design," Proceedings, Aircraft/Pavement Technology: In the Midst of Change, 1997 ASCE Airfield Pavement Specialty Conference, Seattle, Washington, pp. 33-47.

Tutumluer, E. and M.R. Thompson, "Anisotropic Modeling of Granular Bases, Final Report," FAA Center of Excellence for Airport Pavement Research Report No. 2, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 1998.

Wattar, S.W., N.M. Hawkins, and E.J. Barenberg, "Aggregate Interlock Behavior of Large Crack Width Concrete Joints," the Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, New Jersey, April 11-16, 1999.

Zuo, Q.H. and K.D. Hjelmstad, "Bounds and Approximations for Elastic Wave Speeds in Cubic Crystals," *J. Acoust. Soc. Am.*, 101(6), 3415-3420, 1997.

Zuo, Q.H. and K.D. Hjelmstad, "Bounds and Approximations for Elastodynamic Wave Speeds in Tetragonal Media," *J. Acoust. Soc. Am.*, 103(4), pp.1727-1733, 1998.

Zuo, Q.H. and K.D. Hjelmstad, "Piecewise Linear Warping Theory for Multilayered Elastic Beams," *ASCE J. Engrg. Mechanics,* 124(4), pp.337-384, 1998.

Zuo, Q.H. N.N. Hsu, J.S. Popovics, and J.D. Achenbach, "Response to a Suddenly Applied Point Load of Two Layers Overlaying a Half-Space," Offered for publication in Wave Motion.

Information Dissemination and Significant Activities

May 2002

Faculty members and students of the COE participated in the 2002 FAA Airport Technology Transfer Conference, held in Atlantic City, NJ. The COE contributed five papers to the conference, based on recent research in concrete and asphalt airport pavement modeling, and in bird strike hazard mitigation technologies. The five papers presented were:

Hovan, M., and Herricks, E., "Computation of Bird Strike Risks at Airports and Wildlife Strike Mitigation Research Program Update."

Rufino, D., Roesler, J. and Barenberg, E.J., "Evaluation of Different Methods and Models for Backcalculating Pavement Properties Based on Denver International Airport Data."

Gomez-Ramirez, F. and Thompson, M.R., "Superposition Concepts for Considering Stress-Dependent Properties in Airfield Flexible Pavement Analysis."

Bozkurt, D. and Buttlar, W.G., "Three-Dimensional Finite Element Modeling to Evaluate Benefits of Interlayer Stress Absorbing Composite for Reflective Crack Mitigation."

Dickey, A.M. and Newman, A., "Development and Maintenance of Airport Wildlife Hazard Mitigation Website and ARFF Reporting Site for FAA and its Use as a Communications Tool."

Faculty

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Barry J. Dempsey, Director (217-893-0004)
Ernest J. Barenberg, Associate Director (217-333-6252)
Marshall R. Thompson, Associate Director (217-333-3930)

Jan D. Achenbach
Rahim F. Benekohal
William G. Buttlar
Samuel H. Carpenter
Peter S. Chen
Barry J. Dempsey
Neil M. Hawkins
Edwin E. Herricks
Keith D. Hjelmstad
David A. Lange
Ronald P. Larkin
James H. Long
Phillip C. Mankin
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Henrique L.M. dos Reis
Jeffery R. Roesler
David J. Schaeffer
Leslie J. Struble
Erol Tutumluer
Richard E.Warner
J. Francis Young

Northwestern University
Surendra P. Shah

Embry-Riddle Aeronautical University
Archie Dickey

Students

One of the major objectives of the COE is to educate and train students for airport pavement engineering positions with state, federal, and private agencies. The COE is pleased to have a large group of outstanding students involved in airport pavement research and in wildlife strike mitigation research. It is believed that these students will be well qualified to become professional engineers who will design and construct future airport pavement systems.

University of Illinois at Urbana-Champaign

Salah Altoubat	Ph.D., 1997
Hua Ai	Ph.D., 1998
Manuel Bejarano	Ph.D., 1998
In-Soo Eom	Ph.D., 1998
Mohamed Gamel	Ph.D., 1997
Navneet Garg	Ph.D., 1997
Amin Habboub	Ph.D., 1998
Louis Haussmann	M.S., 1996
Mark Jansen	M.S., 1996
Yoon-Jun Kim	Ph.D., 1998
Jagannath Malella	Ph.D., 1998
Trent McPeak	M.S., 1996
EunJae Shim	Ph.D., 1998
Hak-Chul Shin	Ph.D., 1997
Guo-Kuang Sun	Post Doctoral Research Associate
Ertgrul Taciroglu	Ph.D., 1998
Samer Wattar	Ph.D., 1999
Thomas Zehr	M.S., 1996

Northwestern University

Kolloru Subramaniam	Ph.D., 1998
Chunnan Zhou	Ph.D., 1998

Center of Excellence for

Operations Research (NEXTOR)

Established October 1996, Sponsor: ATO-P
FAA Wm. J. Hughes Technical Center

University of California at Berkeley
Massachusetts Institute of Technology
University of Maryland at College Park
Virginia Polytechnic Institute and State University
George Mason University

The Center of Excellence in Operations Research (NEXTOR) was established in 1996 at the University of California at Berkeley (UCB) along with Massachusetts Institute of Technology (MIT), University of Maryland (UMD), and Virginia Polytechnic Institute and State University (VPI). George Mason University became a full partner of this COE in 2003. In this COE, the FAA has access to a consortium consisting of the FAA, airlines, universities, and other private industry partners that are working collectively on business and operational issues of mutual interest and concern. Operations research, as a combined form of science, engineering, and mathematics, offers a highly successful methodology for improvement.

Mathematical techniques and automation tools are being developed in a sophisticated technical setting while simultaneously being formulated as pragmatic near-term solutions to real industry and FAA problems. People, money, laboratories, command and control centers, operational centers, and access to aircraft operations are resources that are being shared in a unique manner via participation in the COE. This collaborative effort allows for enhanced capabilities such as modeling and analysis tools to enable the FAA to improve oversight and assessment. This represents an expansive ability to leverage scarce resources, to augment government capabilities, and to further streamline government processes through the hybrid funding vehicle, grant, and single-source contract awards.

Primary Sponsoring Organization: FAA, ATO-P

FAA COE PM: Tara Carr
Faculty: 28

Prof. Mark Hansen, co-director, UCB (510-642-2880)
Prof. Arnie Barnett, co-director, MIT (617-2670)
Prof. Michael Ball, co-director, UMD (301-405-2227)
Prof. Antonio Trani. co-director, VPI (540-231-4418)
Prof. George Donohue, co-director, GMU (703-993-2093)

Students: 100
Projects: 58

5 Core Team members, 15 Industrial Partners, 11 University Affiliates

COE Industrial Partners

Boeing
California Department of Transportation (Caltran)
Draper Laboratory
Federal Express
Honeywell
Leigh Fischer Associates
Logistics Management Institute
Maryland Aviation Administration
MASSPORT
Metron
Sabre DT
Seagull Technology
SCAG
TASC
Virginia DOT

COE Core Team

University of California at Berkeley

Massachusetts Institute of Technology

University of Maryland

Virginia Polytechnic Institute

George Mason University

COE University Affiliates

Air Force Institute of Technology
Embry-Riddle Aero. University
Naval Postgraduate School
Rensselaer Polytechnic Institute
Princeton University
SUNY at Buffalo
U. of Michigan
U. of Minnesota
U. of Rochester
U. of Southern California
U. Texas at Austin

Projects

AFS Data Warehouse/Library Pilot

The Federal Aviation Administration's (FAA) Office of Flight Standards Services (AFS) is charged with inspecting and collecting safety data for all the flights in the U.S. A number of these databases were characterized by shortcomings in the areas of data quality, data ownership, and lack of functionality. In 1996, the FAA drafted a Project Implementation Plan (PIP) to provide a high-level project plan for tasks necessary to implement a Data Warehouse and Operational Data Store in order to resolve some of these issues.

The focus of this project was to re-evaluate the original project plan, given the rapid emergence of new technologies, and provide a revised strategy for the FAA data issues based on the capabilities of new technologies. In particular, the application of emerging technologies to data analysis, such as the creation of a Knowledge Repository including both Data Library and Data Mining components, has been recommended for the FAA. The most recent phase of the project focused on the design, development, and implementation of a prototype system that embodies these emerging information technologies, with particular emphasis on the concepts of Knowledge Repositories and Data Mining for the purposes of Knowledge Management and Knowledge Discovery respectively. These new technologies have helped the FAA to resolve existing data issues, obtain better insights into historical data, with the ultimate objective of reducing and preventing flight accidents in the future.

Sponsoring Agency: ASD-430
NEXTOR Team: Amar Gupta, MIT

Airports and Air Quality: Emissions, Conformity, and Mitigation

The impact of air quality at airports is being studied through two parallel and closely coordinated research efforts. The first component aims to improve the state of the art in airport emissions modeling. Phase I of this effort will focus on emissions estimation procedures and emissions factors used in the FAA/USAF EDMS model. Fuel consumption, remote sensing, and engine testing data will be used for this purpose. In Phase II, the improved procedures will be applied to develop an emissions inventory for a major California airport, including aircraft, ground support, and aircraft sources. Daily, weekly, and seasonal variation in emissions will be described. The second component of the research estimates changes in airport emissions arising directly or indirectly from airport projects subject to conformity requirements under the Federal Clean Air Act, and identify cost-effective mitigation measures for nonconforming projects. Phase I of this portion of the study will focus on conformity by first considering operational impacts of the project on existing activity, and then by the potential of the project to stimulate new activity. Phase II will assess mitigation measures from the standpoint of both cost-effectiveness and implementation ability.

Sponsoring Agencies: Caltrans, LA World Airports, and San Francisco Airport
NEXTOR Team: Mark Hansen and Rob Harley, UCB

Airport Surface Movement Enhancement/ Runway Incursion Prevention Investment Analysis

This project considers data about U.S. runway accidents, about fatal runway crashes worldwide, and about recent U.S. runway incursions viewed as especially dangerous by pilots and air traffic controllers. Then we ask: based on existing patterns and projected growth in air traffic, how many runway accidents might be expected in the U.S. over the next 20 years, and what consequences might be expected from these accidents? No more than approximate answers can be provided, however, our underlying assumptions can be made explicit so that readers can make their own judgments about the plausibility of the analysis.

The estimates are surprising and disturbing. Properly understood, recent patterns appear to imply roughly 20 fatal runway collisions over 2002-2021 in the U.S. Nearly all of these would involve at least one jet plane, and such jets would suffer fatality rates averaging about 35%. (Among survivors, the fraction with serious injuries would approximate the fraction killed.) Commuter planes, air taxis, and general aviation aircraft would figure in about 3/4 of the fatal crashes, and such ill-fated planes would suffer average death rates near 80%. All tolled, runway collisions could cause the deaths of nearly 1000 people between 2002-2021. This represents nearly eight planeloads of jet travelers, and eight planeloads of travelers on smaller commercial aircraft.

Such numbers are all the more unnerving because, between 1997-99, there was only one fatal event on a US domestic jet, which killed eleven people. There was one commuter plane crash (with 29 fatalities) during the same period. In consequence, it is reasonable to fear that U.S. runway crashes between 2002-21 could cause more deaths and serious injuries than all other causes combined.

However, such an assessment is not a prediction. Rather, it represents the baseline level of threat that new measures—technological and otherwise—must strive to counteract. Similar forecasts could have been made in years past (e.g., about the danger of thunderstorm-induced wind shear), but they did not come to pass because of a multifaceted program that greatly diminished the threat. What this research suggests is the importance of a similar program for US runways.

Sponsoring Agency: ASD-400
NEXTOR Team: Amedeo Odoni and Arnold Barnett, MIT

Analysis of Aircraft Separation and Collision Risk Modeling

NEXTOR is supporting the FAA in a small study to investigate the effects of aircraft separations on collision risk. NEXTOR is just one of several participants in this activity sponsored by FAA and Euro control.

As part of this group, NEXTOR's main task has been to analyze current and future airspace scenarios developed as part of the NARIM model umbrella for understanding the levels of collision risk exposure today and under future Free Flight scenarios. VPI has developed a computer model to study outcome scenarios generated by the FAA (NARIM scenarios), conflicts under no-ATC intervention for current conditions and in the year 2005 scenario, characterization of conflict geometry, and sector loads (per time interval). The idea behind the model is to examine the NARIM flight data, and assuming no intervention, record the collision risk events. Specifically, we classify each intrusion of aircraft B into a proximity shell of aircraft A via the following vector:

[Entry point of proximity shell, exit point of proximity shell, relative headings of A and B, duration of intrusion, and closest distance between A and B during the intrusion]

VPI is working with a subset of the FAA ETMS data (including 4200 flights in the Eastern U.S.) comprising four ARTCC Centers. This study serves as a precursor to the development of a toolbox of models (as proposed in the current Aircraft Separation Standards and Collision Risk Modeling Concept Paper) to quantify the economic impacts of reduced separations and their effect in collision-risk metrics.

Future enhancements to this model can then include a superimposition of ATC intervention strategies and blunder rates in coordination with man-in-the-loop simulations.

Sponsoring Agency: ASD-430
NEXTOR Team: H.D. Sherali and A.A. Trani, VPI

Analysis of Avoidable Enroute Delay Associated with Corridor Integrated Weather System

This research project will assist MIT Lincoln Laboratory (MIT/LL) to analyze the meteorological causes of avoidable en-route connective weather delays. The focus of the project is to conduct detailed analyses of multi-hour data sets of en-route convective weather cases from the Corridor Integrated Weather Systems (CIWS) experiment in 2001.

There will be a quantification of three categories of delays: "avoidable" with perfect predictions, "avoidable delays" with principal meteorological situations and those due to operationally significant errors in the contemporary forecasts. Software will be developed to estimate the delay reduction that could have been achieved with perfect information on the convective weather impacts.

Sponsoring Agency: FAA
NEXTOR Team: Mark Hansen and Avijit Mukherjee

An Analytic Study of Resource-Rationing Methods for Collaborative Aircraft Routing

The Collaborative Decision Making (CDM) effort has shown great promise to enhancing air space utilization through information sharing and distributed decision-making. The objective of the proposed work is to illustrate and quantify the tradeoffs between potential collaborative routing resource rationing approaches as they impact the airlines and overall system efficiency, controller workload, and enroute congestion. Thus far, CDM has been applied principally to the planning and control of ground delay programs. This project is exploring certain questions related to CDM's application to enroute airspace resource allocation. Specifically, alternative resource-rationing methods will be defined and evaluated along several dimensions.

Sponsoring Agency: AUA
NEXTOR Team: Michael Ball
Industry Partner: Draper Laboratories

Analytical Support for Free Flight Phase 1

A team of researchers from UC Berkeley, TASC, and Seagull has worked with the Free Flight Phase 1 (FFP1) Office to support the evaluation of the FAA's FFP1 program. TASC has been developing an Operational Performance Database to support the evaluation. The raw data is compiled from ARTS and HOST tapes, weather databases, and airport logs. From these sources, a database containing extensive metric information for individual flight arrivals, along with information on particular "push periods" at FFP1 airports, has been compiled. Seagull has

studied the expected interaction of two Center TRACON Automation System (CTAA) tools, the Terminal Movement Advisor, and the Passive Final Approach Spacing Tool, when they are employed together.

UC Berkeley has focused on developing and demonstrating methodologies for normalization, valuation, and safety impact analysis. In the normalization work, a variety of statistical modeling approaches have been applied to analyze day-to-day variation in arrival delays at ATL, DFW, and LAX airports. Particular attention has been given to controlling f the effects of weather, demand, and conditions at other airports on LAX operations. Valuation work has centered on developing valuation methods for two aspects of National Airspace System (NAS_ performance—predictability and maximum throughput rates. In the safety area, the research objective is to develop methods for assessing the effects of FFP1 on operational error rates.

Sponsoring Agency: Free Flight Phase 1 Program Office
NEXTOR Team: Mark Hansen, Geoffrey Gosling and David Gillen, UCB,
Industry Partner: TASC and Seagull

Analytical Support for the Global Aviation Information Network

This research project builds on prior NEXTOR research for the FAA Office of System Safety and comprises two activities to support the development of the Global Aviation Information Network (GAIN), a government and industry partnership which promotes and facilitate the voluntary collection and sharing of safety information by and among users in the international aviation community.

The two areas of research that are considered critical to the effectiveness of collecting and analyzing information under GAIN are the development of system safety performance measures based on nonaccident data and improved analytical tools and methods, especially those focusing on flight crew error, the single-most frequent of cause of aviation incidents and accidents.

The first activity under this research is supporting the development of system safety performance measures by assembling information on other ongoing research programs that are relevant to measuring aviation system safety performance, documenting available data sources and analytical resources, and exploring the use of available data to identify system safety performance measures. The second activity continues previous NEXTOR research into the development of the Prototype Flight Crew Human Factors Integration Tool (IT) by updating the accident and incident databases that are accessible using the IT to include the most recent data available from the National Aviation Safety Data Analysis Center, and maintaining the IT website on a server at Berkeley. As part of this research, NEXTOR researchers have been actively participating in two GAIN working groups that are reviewing existing analytical methods and tools and developing a prototype website to support the distribution and sharing of aviation safety information.

Sponsoring Agency: FAA
NEXTOR Team: Geoffrey Gosling and Karlene Roberts, UCB

Airport Noise Analysis with SIMMOD and INM

NEXTOR researchers, in collaboration with the Maryland Aviation Administration, are currently working to integrate the SIMMOD air traffic simulation model and the Integrated Noise Model. The project is intended to develop an integrated noise analysis model for airports. A yet

unfunded goal of the project is to connect the analysis package to a geographic information system. To date, the SIMMOD and INM models have been successfully linked. The Maryland Aviation Administration and the researchers from the University of Maryland are considering further extensions.

Sponsoring Agency: Maryland Aviation Administration
NEXTOR Team: Paul Schonfeld, UMD

Arrival Information Sharing With Airlines

This study concentrated on evaluating the potential benefits of making detailed aircraft arrival information to airlines. It was motivated by the good predictive performance of aircraft arrival support tools such as CTAS, and by evidence that such information may indeed affect the way gates are managed by airlines.

The Airline Sequencing Model (ASM) was built as a mixed integer programming optimization model based on an aircraft turn model that considers timed aircraft arrivals, departure schedule, physical gate resource constraints, and ground crew resource constraints. The model determines an aircraft arrival sequence that minimizes passenger delay. In this model, the taxi-in time is assumed to be constant.

A ground operations model was developed that involves numerous distinct sets of crews conducting distinct activities, including baggage unloading and loading, catering, cleaning, maintenance, passenger deplaning and boarding, and so forth. During visits to airline ground operations centers, key airline personnel indicated that the baggage handling process could be one bottleneck in the turn process. Therefore, baggage handler constraints were included in the ground operations model. A number of additional constraints are included in ASM to restrict the landing and arrival-at-gate times. Another important consideration in the model is airline fairness, meaning, ASM guarantees that an airline does not improve its operational performance at the expense of another airline. Fixing the airline's landing times in the model enforces airline fairness; an airline is allowed to shuffle aircraft landing times only within its own set of input landing times. Finally, ASM considers gate compatibility and availability. An arriving aircraft can only access the gate area if a gate compatible with its aircraft type is available.

The results indicate that the potential benefits from increased communication and collaboration during the aircraft arrival process could be significant. Decreasing the standard deviation of the landing time estimate error can also reduce passenger delay by a significant amount. Allowing an airline to shift an aircraft's landing time by five minutes can reduce even more passenger delay.

Sponsoring Agency: NASA Ames Research Center
NEXTOR Team: Eric Feron, MIT

Baseline Estimates of Gate-to-Gate Travel Times

A detailed analysis of gate-to-gate times for 20 of the busiest airports in the United States has been performed for all flights recorded in the ASQP database between 1995 and 2000. The objective is to demonstrate how to develop "baseline" estimates of gate-to-gate times for individual city pairs. These baseline estimates can then be used to monitor the evolution of flight delays over the years. The analysis has yielded meaningful and interesting results that will be reported in a forthcoming master's thesis. The thesis also (1) separately analyzes various aspects of reported taxi-out, airborne, and taxi-in times and (2) develops a probabilistic model that illustrates the trade-offs that airlines must make in setting the scheduled block time for each individual flight.

NEXTOR Team: Amedeo R. Odoni and Yasmine El Alj

California Aviation Database

The California Aviation Database (CAvD) project was suggested by the Caltrans Aeronautics Program to fulfill a need of the planners involved in aviation system planning and programming activities to locate and access aviation data in an efficient and comprehensive way. It is implemented in the form of a website. Information includes links to related websites, bibliographical listings, and results of original NEXTOR research. CAvD is currently intended as a 5-year project. CAvD is a joint project between the National Center of Excellence for Aviation Operations Research (NEXTOR) and the California Department of Transportation (Caltrans). Its primary audiences include Caltrans and other state, regional, county, city, and airport agencies. The site is now under construction and can be accessed at http://www.its.berkeley.edu/nextor/Cavd.

Sponsoring Agency: Caltrans
NEXTOR Team: Jacob Tsao, Mark Hansen and Geoffrey Gosling, UCB

Caltrans-NEXTOR Industry Partner Program

UCB and Caltrans formed a West Coast Partnership of aviation-related professionals in California to establish aviation research based on common interests. The current 3-year contract will focus on the development and use of operations research: a focused blend of applied mathematics, computer science, and engineering aimed at finding optimal solutions to complex problems. The work undertaken will address issues in measures, safety data analysis' scheduling, workload management and distribution, navigation, communications, data collection and distribution, and aviation economics.

Continuing projects will include updating the California Aviation Database (CavD) and issuance of the *State of the System Report*, coordinating meetings with the West Coast Partners and providing publications and summary statements of the Center's operations. The work under this Interagency Agreement will be conducted over a 3-year period ending in June 2004.

Sponsoring Agency: Department of Transportation, New Technology and Research
NEXTOR Team: Mark Hansen and Geoff Gosling, UCB

Center Sector Tools Descent Advisor Research

This project involved two tasks:

1. The first task assisted in the assessment of flight-efficiency benefits derived from the Center Sector Tools, under development at NASA Ames Research Center. The sector tools are air traffic control automation tools, evolved from the Center-TRACON Automation System Descent Advisor, designed to assist enroute controllers in the efficient management of traffic. The research was conducted in two phases that would provide preliminary order-of-magnitude assessment of the economic benefits of the Tools on a national basis, together with a more detailed analysis based on national airspace analysis.
2. The second task assisted in the algorithmic improvement of the Trajectory Synthesis (TS) software under development at NASA Ames Research Center. The TS is the fundamental building block of the Center-TRACON Automation System (CTAS) designed to assist controllers in the efficient management of air traffic, which provided CTAS with accurate 4D trajectory predictions. Improvements in the algorithms were needed to model cruise flight at constant pressure altitude under nonstandard atmospheric conditions. In addition, algorithm improvements were needed which retain the accuracy of the current high-fidelity model while reducing the computational load resulting from the fidelity of the trajectory modeling coupled with the density of atmospheric data.

More detailed information can be found in NEXTOR Research Reports RR-97-1, "Preliminary Investigation of Sector Tools Descent Advisory Potentials Benefits" and RR-97-2, "Non Standard Day Effects In ATM Trajectory Simulation" These reports are available through the NEXTOR program office.

Sponsoring Agency: NASA Ames

NEXTOR Team: Mark Hansen and Adib Kanafani, UCB
Industry: Seagull Technologies
Collaborative Decision Making (CDM) and Free Flight Phase 1 & 2

a. Arrival Flow Uncertainty Analysis

The ability to plan and control ground delay programs (GDPs) is hampered by the high degree of uncertainty associated with the arrival flows into the GDP airport. The three sources of uncertainty are unreported flight cancellations; pop-up flights, whose operation is not known sufficiently in advance to allow for inclusion within the planning process; and drift, the either forward or backward deviation of the timing of a flight relative to the timing used in the planning process. NEXTOR is developing models to evaluate the impact of various sources of uncertainty. Such models will also allow investigation into the causes of this uncertainty and the development of approaches to mitigating the adverse effects of uncertainty.

b. Decision Making in the Context of Weather Uncertainty

Current TFM approaches generally are based on a single weather scenario. In the enroute airspace, evolving technologies such as the playbook and the Collaborative Convective Forecast Product (CCFP), usually lead to decision-making in which a portion of airspace is either considered usable at its full capacity or entirely unusable. It has been shown that better decision-making can result when weather uncertainty is explicitly taken into account and when it is acknowledged that portions of weather-impacted airspace can sometimes handle traffic flows that are less than full but nonetheless significant. NEXTOR is enhancing decision models previously developed at the University of Maryland and MIT to take into account new weather information becoming available and evolving weather products such as CCFP. A new generation of models that deal explicitly with the increasing quality of forecasts over shorter time horizons is also being developed.

c. Congestion Prediction Models

A fundamental element in any approach to effective TFM is the prediction of airspace congestion. Congestion occurs when there is a capacity-demand imbalance. Reduced capacity is most often the result of weather events. Increased demand usually occurs when earlier, upstream problems lead to later demand surges or when relatively remote weather events lead to a cascading of reroutes and congestion into areas of no adverse weather activity. Airspace users and managers have little hope of formulating effective plans to avoid congestion without accurate predictions of when and where congestion will occur. The current mechanism of this type, monitor alert, suffers from several deficiencies: it is deterministic, i.e., assumes flights take-off exactly when planned and proceed through the airspace using planned speeds and trajectories; it does not account for the system effects of congestion, i.e., congestion in one portion of the airspace will delay the time at which flights arrive to a downstream portion of the airspace; and it employs a simplistic airspace capacity model, i.e., it issues an alert when the number of flights in an area is predicted to be larger than a simple threshold value.

NEXTOR is developing new models that aim at improving the prediction, both in the near-term (e.g., ½ hour in advance), and in the long-term, (e.g., 3 or 4 hours in advance), of those portions of the airspace and the associated time periods when capacity-demand imbalances will occur unless changes in current FAA and airline plans are made. The goal is to provide information that is, in form and content, useful both to the airlines (and other airspace users) and to the FAA.

d. Resource Rationing Methods and Evaluation

Effective management of the enroute airspace requires a rich information exchange and the distribution of decision-making responsibilities among airspace users, the ATCSCC and the regional traffic flow management units. An essential component of achieving such effective management is the development of resource-rationing methods that effectively allocate decision-making responsibilities among airspace users and the various airspace managers and encourages airspace users to provide intent information in a timely manner. Such rationing methods, which are embodied in the ration-by-schedule and the compression algorithms, represent a fundamental component in the successful application of CDM to the planning and control of GDPs. Due to the various complexities of the enroute

environment, the GDP methods cannot be directly applied, therefore, new approaches that embody the principles and spirit of the CDM GDP methods are required. NEXTOR has formalized a set of resource rationing methods for the enroute airspace and is carrying out a comparative analysis of these methods. The set of alternatives being evaluated takes into account, and builds upon, the work generated by the CDM long-term Collaborative Routing Group. This research is being coordinated with related activities at Metron and Mitre CAASD.

e. Real-Time Resource Auctioning

As demand for air travel steadily grows, it becomes increasingly obvious that the demand for certain key NAS resources is much larger than their capacity. These scarce resources have become extremely valuable, which suggests that economic principles should be applied to their allocation. Ad hoc allocation methods lead to less efficient resource use. NEXTOR is conducting research into the use of auctioning concepts as a dynamic resource allocation mechanism. Specifically, it is characterizing the principles underlying ration-by-schedule and compression and using these to develop next generation approaches that can be applied both to GDP planning and to enroute resource allocation.

Sponsoring Agency: AUA
NEXTOR Team: Michael Ball, UMD
Mark Hansen and Jim Evans, UCB
Amedeo Odoni, JP Clark, Husni Idris, Rani Bhuva, and Laura Kang, MIT
Toni Trani and Hanif Sherali, VPI
Industry Partner: Metron

Communications Expert

NEXTOR provided analysis of responses from companies with interests in the manufacture of radio communications equipment and the provision of voice and data communication services to aircraft. The Virginia Tech group also analyzed the benefits and disadvantages of using satellite communications links for air traffic control voice and data communication and reviewed the supporting documentation presented to the JRC on May 5, 1998.

Sponsoring Agency: ASD-410
NEXTOR Team: Timothy Pratt, VPI

Complexity Models and Metrics for the Support of Air Traffic Management Tools & Operations—Dynamic Density and Resectorization

This project recognizes that airspace and traffic complexity as being key limitations in the current operation of the NAS. For reasons of safety, it is important that the level of traffic complexity in any sector does not exceed the capabilities of the controllers to safely and reliably manage traffic. Because of a lack of understanding of the real basis for cognitive complexity in air traffic control, only the crudest metrics for complexity (e.g., number of aircraft in a sector) are used to manage complexity.

The goal of this research is to first identify and, second, potentially adapt methods from other disciplines as complexity metrics. These modeling approaches would then be evaluated for their applicability to current airspace and airway structures. These same evaluation tools would be appropriate for reporting changes in airspace or operations, both in the short term (e.g., Dynamic Resectorization) and in the long term (e.g., Airspace or Airway Redesign). One unique aspect of the proposed research is that it will be conducted in parallel with CENA in France.

Sponsoring Agency: FAA
NEXTOR Team: John Hansman, MIT

CPDLC Benefits Assessment and Extensibility Analysis

The Virginia Polytechnic Institute and the University of California, Berkeley will serve as co-leads in this research project. The Massachusetts Institute of Technology will serve in a consulting role with the University of Maryland contributing with the participation of a post-doctoral researcher at UCB.

Two areas of research will be explored.
1. Area 1 will set the baseline on how operations in the nonintegrated FFPI environment in 2005 will be conducted. Deficiencies and problems caused by the non-integrated nature of the toolsets will be described. Initially, there will be an analysis of benefits of the independent implementations of the decisions support tools URET and TMA and the implementation of the data link. Research focus will be in the extrapolation of how the benefits would occur in an integrated data link—decision support tool environment.

2. Research area 2 is to assess the benefits of the implementation of a data link service integrated with the passive FAST decision support tool, which will be in place in the 2005 time frame as part of FFP1. This implementation of data link services will represent the first application of air traffic control data link in a terminal environment. The challenge will be synthesizing, postulating and defending the benefits from utilization of both tools, the FAST decision support tool and the data link service in a terminal environment.

Sponsoring Agency: FAA
NEXTOR Team: Mark Hansen and Jasenka Rakas, UCB
Toni Trani and Dusan Teodorovic, VPI
John Hansen, MIT

CTAS Analysis Tasks

The CTAS has been developed by NASA to provide tools to assist air traffic controllers in planning and controlling arriving air traffic. The human air traffic controllers, automation aids (like CTAS and other monitoring equipment), and the procedures that govern their operations, together constitute a reactive system that evaluates the process outputs, estimates the current state of the process, selects a control strategy to achieve system objectives (i.e., maintain aircraft separation, maximize airport throughput, obey safety constraints), and provides the necessary process inputs. Furthermore, this system is a hybrid system, since it performs not only continuous transformations of input and output data (such as trajectory prediction) but also includes complex decision logic for selecting the appropriate control strategy using the defined procedures (for example, the runway allocation decision trees in FAST). Hybrid systems present unique challenges in their design, analysis, and implementation.

The objective of this study is to present a range of technologies that address the safety concerns that arise in the current air traffic management system and as a result of expected changes in the system. CTAS has been used as an example of the type of system for which safety assessments must be made.

A general framework for the modeling, specification, and analysis of the CCTAS is presented in the reports RR-97-5, “Modeling, Specification and Safety Analysis of CTAS” and RR-97-6 “Formal Specification and Analysis of the

Center-TRACON Automation System (CTAS)" respectively. They are available in the NEXTOR Program Office.

Sponsoring Agency: NASA Langley
NEXTOR Team: Shankar Sastry, UCB
Nancy Lynch, MIT
Darren Cofer, Honeywell
Industry Partner: Honeywell

Degradable Schedules

The airline scheduling systems used today are intended to create optimal (i.e., revenue maximizing) schedules based on a number of factors, including aircraft availability and crew scheduling. Once deployed, however, these schedules are often far from optimal, as they do not take into consideration the weather and air traffic control delays that arise during operation. NAS disruptions can have a severe impact on the operations of airlines. Several scheduling approaches are being investigated to improve schedule robustness. Options include independent aircraft routings, virtual hubs, and incremental schedules.

Sponsoring Agency: Sabre (partial)
NEXTOR Team: John-Paul Clarke, Flora Garcia, Laura Kang, and Michelle Karow, MIT

Deployment of Aviation Security Technologies

The FAA was commissioned to purchase and deploy aviation security technologies in airports throughout the United States. The challenge was to determine the impact (measured by security performance and cost) of deploying these various security devices. This issue is addressed in the Deployment of Aviation Security Technologies project. NEXTOR researchers at Texas Tech and the University of Illinois must define meaningful system performance measures, describe relationships between them, and determine their impact on passenger safety. They must also develop discrete optimization mathematical models that describe and capture the problem of how to ensure maximum security while maintaining acceptable throughput rates and remaining within budget. It is necessary, then, to apply heuristic procedures to provide practical solutions. This project is now completed.

Sponsoring Agency: FAA
NEXTOR Team: John Kobza, Texas Tech; Sheldon Jacobson, U. of Illinois

Development of Massport Planning and Tactical Response Capabilities for Irregular Operations

Members of the NEXTOR project, Development of Massport Planning and Tactical Response Capabilities for Irregular Operations, seek to determine how Logan Airport interacts with other agencies in the National Airspace System (NAS). Team members are interested in exploring how changes or disruptions in the activities of other agents are likely to affect Logan Airport. Assessing the quality and quantity of information available for irregular operations planning, the sources of that information, and the prediction tools available, is vital to the examination of the relationship between Logan Airport and the other NAS agents. Researchers are interested in determining the infrastructure required for real-time adaptive operations. The ultimate objective of the project is to demonstrate the potential benefits of monitoring the activities of other NAS agents through implementation of a prototype prediction methodology in controlled case studies.

Sponsoring Agency: Massachusetts Port Authority
NEXTOR Team: John-Paul Clarke, MIT

Development of an Action Plan for Integration of System Safety Performance Measures and Risk Assessment

This research project builds on prior NEXTOR research for the FAA Office of System Safety on system safety performance measures and is undertaking a scoping study to support the subsequent development of an action plan for integrating system safety performance measurement and risk assessment. The objective of the action plan is to identify and measure the full range of risks that impact system safety as well as assess the potential contribution of alternative means of reducing those risks. The scoping study will identify the issues that such a plan would need to address and the information resources available to support an integrated approach to system safety risk management. Since a comprehensive approach to risk management within the aviation system involves a large number of different offices within the FAA as well as an even larger number of stakeholders in the wider aviation industry, the development of an effective action plan needs to take account of both on-going activities and planned future activities within this broader institutional context. The research will include a review of relevant literature on system safety risk assessment, as well as structured interviews with representatives of the various stakeholder groups.

Sponsoring Agency: FAA
NEXTOR Team: Geoffrey Gosling, UCB

Development of Fast-Time Simulation of Techniques to Model Safety Issues in the National Airspace

The objective of this NASA-funded project was to build on the open architecture features defined by previous NEXTOR/ATAC research to examine the type of safety issues that could appropriately be modeled by fast-time simulation and to develop relevant modeling techniques. The project undertaken, for the NASA Aviation Safety Program, by a team led by the ATAC Corporation that includes NEXTOR researchers at Berkeley and MIT. The research is developing and testing prototype behavioral models for both pilots and air traffic controllers as well as data analysis routines that would need to be incorporated into fast-time simulations in order to predict safety effects of changes in procedures or technologies and to support risk assessment. The work is divided into three phases. The first phase involved a review of existing models of human performance and potential incorporation of these concepts into fast-time simulation, as well as a demonstration of the application of these concepts using *SIMMOD PRO!*, a proprietary enhancement of the FAA Airport and Airspace Simulation Model. Phase two involved the simulation of controller and pilot behavior using the NASA-developed Man-Machine Integration Design and Analysis System (MIDAS) software to demonstrate the incorporation of human performance into fast-time simulations for investigation of safety issues associated with airfield operations. The third phase, which is currently under way, involves the development and integration of prototype human performance simulation modules of controller and pilot behavior into a fast-time simulation of air traffic operations using a reconfigurable simulation environment developed by researchers at Georgia Institute of Technology. This phase is examining safety issues associated with aircraft encounters with clear air turbulence in an enroute environment. A report detailing the Phase 1 findings was published in December 1999, and a report presenting the second phase results was published in December 2000.

Sponsoring Agency: NASA
NEXTOR Team: Mark Hansen and Geoffrey Gosling, UCB
John Hansman, MIT
Industry Partner: ATAC

Development of Stochastic Models and Modules and Interactive Communication Capabilities for the MIT Extensible Air Network Simulation

The Aerospace Operations Modeling Office at the NASA Ames Research Center needs probabilistic agent models for analysis and development of the NAS and methods and tools for probabilistic understanding of NAS simulations. Analyses of complex systems, such as the NAS using purely analytical techniques (such as queuing theory), are often limited by the simplifying assumptions required to achieve tractability. Thus, simulation techniques are often employed as a means of predicting the behavior of complex systems. In December 2000, MIT began development of the MIT Extensible Air Network Simulation (MEANS) to support the exploration, development, and evaluation of air traffic management (ATM) concepts. Emphasis in the model is on flexibility, modularity, and the ability to easily simulate uncertainty and other probabilistic phenomena. Two areas of research that build on the existing capabilities of the MIT simulation have been identified in response to the needs of the Aerospace Operations Modeling Office. These are (1) development of stochastic models and modules, and (2) development of interactive communication capabilities.

Sponsoring Agency: NASA Ames

NEXTOR Team: *John-Paul Clarke, MIT*

Enhancements to SIMMOD

NEXTOR Research Report RR-97-8 "Enhancements to SIMMOD: A Neural Network Post-processor to Estimate Aircraft Fuel Consumption" by A.A. Trani and F.C. Wing-Ho, was completed and delivered to the FAA in December 1997. It details the findings of a study conducted at Virginia Tech to improve the accuracy and flexibility of SIMMOD's fuel burn postprocessor. A neural network model was developed to estimate fuel consumption of sample aircraft. Results were compared to the actual performance provided in the aircraft performance manual and found to be accurate within 2%. The model developed can be implemented in SIMMOD and other fast-time simulation programs.

NEXTOR Research Report RR-97-9, "Development of an On-Site Ground Operations Model for Logan International Airport," by E. Feron and B. Declare was completed and delivered to the FAA in December 1997. It details the findings of a study conducted at MIT to model Boston Logan Airport's ground operations. Using SIMMOD was particularly challenging in modeling Logan Airport's operations due to the complex layout of runways and taxiways.

Sponsoring Agency: ASD-430
NEXTOR Team: A. Trani, VPI
G. Gosling and M. Hansen, UCB
E. Feron, MIT
P. Schonfeld, UMD

Evaluation of Airline Industry and Competitive Market Conditions Affecting Logan Airport

The objective of this project was to recommend to Massport an overall approach for more routine and systematic evaluations of airline industry and market conditions that might affect Logan Airport. Phase one of the project was completed in 1998. Phase one identified the types of information about airlines, industry trends, competitive conditions, and detailed market activities that would be valuable to the Aviation Planning Department and Massport. NEXTOR team members constructed a prototype of an evaluation and reporting process that could be repeated quarterly to provide the Aviation Planning Department with a comprehensive overview of recent airline and airport competitive trends. Phase two of the project was completed in early 2000. This phase involved refining and updating the recommended reporting framework from phase one to reflect current data and realistic availability. NEXTOR team members developed a detailed implementation plan that will allow Massport to generate reports quarterly. This includes databases, statistical tools, information technologies, and manpower resources required.

Sponsoring Agency: Massachusetts Port Authority
NEXTOR Team: Peter Belobaba and Amedeo Odoni, MIT

The Feasibility of Using Low Earth Orbit (LEO) Satellite Systems for Air Traffic Control Communications

LEO satellite systems such as Iridium are now becoming operational. These systems offer significant advantages over traditional (GEO) systems that employ satellites in geosynchronous orbits. Of particular interest to aeronautical communications is the drastic reduction in communications delay. Since LEO systems would seem to have natural advantages for air-ground communications, various efforts have been initiated to develop standards and

requirements for their use in this setting. The NEXTOR project is focusing on the evaluation of various hybrid communications architectures in which LEO satellite systems are used to augment ground-based systems. Some of the roles being investigated for LEO systems are as follows:

- providing coverage where ground-based systems are not feasible, e.g., over water and in remote areas such as parts of Alaska,
- augmenting the capacity of ground-based systems, and
- reducing redundancy requirements for ground based system.

The NEXTOR effort will concentrate on comparing alternatives by evaluating system-wide metrics of various architectures.

Sponsoring Agency: AUA-570
NEXTOR Team: Michael Ball, UMD

Human Factors Support to FAA Office of System Safety

This project was directed at three objectives: research into ways to improve the use of human error models within the analysis of aviation safety data; identification of user requirements for enhancements to the prototype Integration Tool, a website-based tool to access, integrate, and analyze flight crew human factor data; and development of statistical analysis techniques using data generated by the current version of the Integration Tool. A prototype instrument to obtain data on individual, team, and organizational factors used with existing aviation safety databases was developed and discussed with safety data analysts within the industry. A survey of data access needs by aviation safety data analysts was designed and distributed to selected respondents in the industry. Embry-Riddle Aeronautical University and UC Berkeley developed statistical analysis procedures to use with both the National Transportation Safety Board accident and incident data and the FAA Pilot Deviation System data. Embry-Riddle also undertook a training needs assessment at several flight training centers.

The results of the research are documented in NEXTOR Research Report RR-98-10, "Development of the Flight Crew Human Factors Integration Tool," Research Report RR-98-11, "Implementation of Analysis Methods and Training Needs Assessment," Research Report RR-98-12, "Improving the Representation of Human Error in the Use of the Flight Crew Human Factors Integration Tool," and Working Paper WP-98-2, "Proposed Functional Enhancements for the Flight Crew Human Factors Integration Tool." These are available from the NEXTOR program office.

Sponsoring Agency: ASY-200
NEXTOR Team: Karlene Roberts and Geoffrey Gosling, UCB
James Blanchard and Deborah Osborne, Embry-Riddle

Impact of AATT Technologies on Air Traffic Management Concept Definition

This project involved two tasks: the first task was to define and document the probable evolution of the NAS through the year 2015, based on current documents and on-going work by the FAA, NASA, and industry. The work involved interaction with major ATM stakeholders and documented the definition of the ATM system evolution as of the end of the reporting period. The second task studied the impact of technologies being developed under the NASA Advanced Air Transportation Technology (AATT) program on the overall definition of the future ATM system concept. This task defined and documented the systems concepts being developed under the AATT program and documented how these concepts would be implemented within the

context of current ATM modernization plans.

More information about the themes in this project can be found in NEXTOR Research Reports RR-97-3, "Air Traffic Management Concept Baseline Definition" and RR-97-4, "National Airspace System Stakeholder Needs." These reports are available through the NEXTOR program office at UC Berkeley.

Sponsoring Agency: NASA Ames
NEXTOR Team: John Hansman and Amedeo Odoni, MIT
Mark Hansen and Adib Kanafani , UCB
Industry Partner: Boeing and Seagull Technologies

Influence of Capacity Constraints on Airline Fleet Mix

This project explored how airport capacity constraints at Los Angeles International Airport (LAX) are likely to influence future trends in fleet mix and load factors, and what policy options exist to influence these trends. The research addressed these issues through three analyses. The first analysis examined recent trends in the regional airline traffic serving the airport and the impact of these trends on the number of aircraft operations at LAX. The second analysis addressed trends in aircraft size and flight frequency in both high-density and lower-density markets in the California Corridor, western states, and transpacific markets, in order to understand how airlines choose between increasing frequency or increasing aircraft size. The third analysis focused on flight frequency and aircraft size trends in a broad range of domestic markets subject to varying levels of airport congestion, including Northeast Corridor markets subject to slot limitations. The analysis will also develop models to predict the effects of airline competition and capacity limitations on flight frequency and aircraft size at a market level, as well as which markets are likely to be served by regional airlines. The results of these analyses were used to explore likely future trends in aircraft size at Los Angeles International Airport, and the likely effects of alternative policies to encourage the use of larger aircraft. The project began in May 1999 and was completed in September 2000.

Sponsoring Agency: Los Angeles World Airports
NEXTOR Team: Mark Hansen and Geoffrey Gosling, UCB

Integration of Reusable Launch Vehicles into Air Traffic Mgmt. (Phase IV)

Update: Analytical and empirical modeling of the impact of restricted airspace on traffic flow and recommendations for airspace allocation for space operations.

NEXTOR Team: *James Kuchar and John Falker, MIT*

Intermodal Operations for the Air Freight Industry through Intelligent Transportation

NEXTOR researchers for the Intermodal project seek to understand the air freight industry's need for efficiency improvement in ground transportation and intermodal-transfer (mode-changing) operations, measure the performance of these operations at selected locations, and identify opportunities for applying Intelligent Transportation Systems (ITS) technologies. The project involves working to understand the present state of intermodalism and adoption of ITS technologies in the industry as well as ascertaining, in quantitative terms, if and why the industry has been adopting ITS-type technologies at a faster pace than other segments of the goods movement industry. The project ultimately would suggest ITS deployment strategies for other segments of the

freight industry. The Intermodal project is on going. Working Paper WP-99-3 is available at the NEXTOR program office.

Sponsoring Agency: Caltrans
NEXTOR Team: Jacob Tsao, Geoff Gosling, Mark Hansen, and Adib Kanafani, UCB

Investigation on the Integration of Airfield and Airspace Simulation Models through an Open Systems Architecture

This NEXTOR project, funded by industry partner ATAC Corporation, seeks to review the current state of the art of incorporating open architecture principles into existing airport and airspace simulation models, and develop recommendations for the most appropriate way to provide these capabilities in future versions of the FAA Airport and Airspace Simulation Model (SIMMOD). The issues associated with providing users with the capability to intervene in the logic of such models during model execution and access intermediate data flows are being explored through a case study approach addressing the impact of new air traffic control technology (the Center-TRACON Automation System) and improved ground movement logic using the current version of SIMMOD.

The research is divided into three phases. The first phase reviewed the current state of the art of open architecture principles in existing airspace and airfield simulation models and implementation issues of how to integrate inputs from various sources. This phase also included a review of a proposed open system architecture termed the SIMBUS concept, as well as development of a detailed work plan for the case study analysis in Phase 2. The second phase includes analysis of existing SIMMOD model structure, the case study analysis, and development of preliminary recommendations for the best way to provide an open architecture within the SIMMOD code. Reports documenting the findings and recommendations of the second phase are currently being finalized. The third phase, which has commenced, is exploring the implementation of open architecture techniques for airport and airspace simulation by examining how to implement controller and pilot behavior modules being developed under a related research project funded by NASA using SIMMOD *PRO!*. This phase of the research will define common constructs for these and other future modules, and compare these constructs to those adopted in other airspace simulation models that currently use an open architecture approach, such as the FAA National Airspace System Simulation Model or the Euro control Reorganized ATC Mathematical Simulator.

Sponsoring Agency: ATAC
NEXTOR Team: Mark Hansen and Geoffrey Gosling, UCB
Antonio Trani, John Kobza, and Hanif Sherali, VPI

Investment Analysis Support

This project provides safety benefits analysis support in the investment analysis effort on airport surface safety initiatives and on airport enhancement strategy analysis. It also reviews the methodology used to determine the effectiveness of ASDE-X multilateration technology, as well as reviews categorization of the severity of surface incidents and accidents, and examines

methodologies developed to understand and quantify the risks and effectiveness of proposed airport enhancement strategies.

Sponsoring Agency: FAA
NEXTOR Team: Arnold Barnett, MIT

Modeling a Large-Package Sort Facility

This project addresses issues related to the design of an airfreight hub for sorting of large packages, i.e., packages that are too big for automatic processing on conveyer belts and need to be handled using forklifts. The focus of this research is the development of analytic models for comparing alternate facility design strategies and options and for setting certain parameters associated with the designs chosen.

Sponsoring Agency: Federal Express Corporation
NEXTOR Team: Larry Bodin and Michael Ball, University of Maryland

Next Generation Satellite Systems for Aeronautical Communications

The introduction of Next Generation Satellite Systems (NGSS) into the global telecommunications landscape offers the potential to revolutionize how consumers and business entities communicate in the future. Aviation is also currently undergoing major changes in its telecommunications infrastructure with modernization efforts underway to convert from the current analog, primarily voice-based system, to a digital voice and data link system for both Air Traffic Management (ATM) as well as airline operational (AOC)-type communications. The future air-ground aeronautical telecommunications infrastructure will be a hybrid, made up numerous terrestrial and space-based links such as VDL-Modes 2 and 3, Mode S, SATCOM, HF to name a few. Each of these will have their own specific link characteristics in terms of technical performance and cost as well as applicability to aircraft platform. Traditionally, air-ground aeronautical communications in domestic airspace has been considered primarily from the ground-based provider's perspective. The application of NGSS systems for aviation offers the potential to greatly change how aeronautical communications is performed in the future. NGSS stands to offer a new alternative to the mix of candidate communications links for future ATM and AOC communications.

This project had two inter-related goals. The first was to assess future aeronautical communications applications. Our work developed a traffic scenario for the year 2020 and then estimated associated bandwidth requirements for advanced weather applications. Included is a model in which aircraft act as sensors and feed back readings, which are fused by a weather model. The resultant weather information would then be sent to all interested aircraft.

The second goal involved the investigation of next generation satellite technology to support these advanced applications. We developed a model that supports the comparison of broadcast, uni-cast, and hybrid broadcast/uni-cast satellite systems for the delivery of weather and other information to aircraft. This model allows for the estimation of the bandwidth requirements for future aeronautical communications applications. It also supports the comparison, based on bandwidth requirements and processing cost, of broadcast or hybrid LEO/MEO architectures, broadcast or hybrid GEO architectures, and general unit-cast architectures.

Sponsoring Agency: NASA Glenn Research Center
NEXTOR Team: Michael Ball, UMD
Antonio Trani, VPI

New World Aviation Safety

This research analyzed the mortality risk of air travel between 1987-96 on jet airlines around the world (except those in the former Soviet Union), and on U.S. commuter airlines. The goal was to provide a baseline cardiogram about air safety at a time that initiatives are under way to improve that safety (e.g., the Global Aviation Information Network). Among the specialized topics considered were:

- how to measure air safety (and how not to do so)
- volatility of mortality-rate statistics given the rarity of fatal crashes
- the safety of new-entrant jet carriers
- the relative safety of auto trips and commuter flights
- whether US airlines are still the safest in the world
- whether an ecological fallacy leads to exaggerated perceptions of the risks of flying on developing-world carriers

NEXTOR Research Report RR-97-9, "Airline Safety: The Recent Record" is available through NEXTOR's Administrative Office (UC Berkeley).

Sponsoring Agency: ASY-200
NEXTOR Team: Arnold Barnett, MIT

Preliminary Study of In-Flight Replanning (previously titled: Airborne-Based Conflict Probe)

This project (sponsored by NASA Langley) focused on identifying issues and areas for additional research related to in-flight replanning, due, for example to weather, traffic congestion, or unexpected winds. MIT examined shorter-term replanning and cockpit-centered issues (e.g., display requirements and pilot preferences) while Honeywell collected data from AOC and focused on moderate-timescale and strategic replanning issues. Models of the replanning process and for the requirements for each stage during replanning were developed to aid in understanding and describing replanning.

Honeywell (with cooperation from American Airlines) performed interviews of AOCs to determine the principal issues for further study from the airline standpoint. In parallel, MIT distributed a survey to pilots using the World Wide Web, and received over 300 responses discussing issues related to cockpit decision-making. Principal results of the MIT survey describe the degree of pilot reliance on pilot reports when formulating diversions due to turbulence or severe weather.

The following reports are available through the NEXTOR Program Office: NEXTOR Research Report RR-98-4 "Preliminary Study of In-Flight Replanning Performed on the Flight Deck," and Report RR-98-3 "Airborne-Based Conflict Probe."

The following two presentations of this work were also made:

- Fan, T., Hyams, D., and J. Kuchar, "Study of In-Flight Replanning Aids," AIAA Guidance, Navigation, and Control Conference, Boston, MA, August 10-12, 1998.
- Hyams, D., Fan, T., J. Kuchar, "Survey of In-Flight Replanning Performed on the Flight Deck", 17th Digital Avionics Systems Conference, Seattle, WA, November 4-6, 1998.

Sponsoring Agency: NASA Langley
NEXTOR Team: James Kuchar, MIT
Bill Corwin, Honeywell
Industry: Honeywell

Positive Passenger Baggage Matching

On September 9, 1996, the White House Commission on Aviation Safety and Security issued its initial report dealing with aviation security matters. Based on the report, the President directed that steps be taken to determine the best means to implement domestic positive passenger baggage matching (PPBM). The FAA, therefore, set up a team to perform research on the subject. The PPBM charter specified that the NEXTOR, with its "highly regarded intellectual qualifications," be "wholly responsible for the technical methodology and approach" of the study, which culminated in a 2-week live test of domestic PPBM that involved 11 airlines, 8000 flights, and nearly 750,000 passengers.

The NEXTOR team played a central role in devising, monitoring, and analyzing a major aviation policy experiment, aimed at investigating what economic and operational effects would arise if the positive bag-match security measure were implemented on U.S. domestic flights. NEXTOR has completed its work on this subject.

Sponsoring Agency: AAR-500
NEXTOR Team: Arnold Barnett and Amedeo Odoni, MIT, Adib Kanafani, Mark Hansen and Geoffrey Gosling, UCB, Robert Shumsky U-Rochester

Noise Impacts for BWI Development (Tasks 2a and 3)

In this project we are integrating noise analysis (based on the INM model) and a geographic information system (ARCVIEW GIS) to estimate the noise effects of various airfield configurations and air traffic forecasts. Noise alleviation alternatives will then be comparatively assessed.

Sponsoring Agency: Maryland Aviation Administration
NEXTOR Team: Paul Schonfeld, University of Maryland

Probalistic Weather Forecasts and Decision Models to Support Ground Delay Program Planning at San Francisco Airport

Uncertainty related to both air traffic demand and the capacity of airspace and airport resources represent very significant challenges to effective air traffic flow management. One of the principal objectives of the collaborative decision making (CDM) effort has been to improve information accuracy, which, in turn, reduces the level of demand and capacity uncertainty. Recently, a prototype forecast product was installed at SFO. This product specifically addresses forecasting fog burn-off times. In this project, NEXTOR is developing methods for producing probability distribution functions for the airport acceptance rate from this new forecast product. It is also investigating and testing methods for integrating these distribution functions into the CDM decision support models.

Sponsoring Agency: AUA
NEXTOR Team: Michael Ball
Industry Partner: NCAR

Program Office

Since NEXTOR's inception in 1996, there has been a growing collaboration of core and affiliated academic institutions, government, and industry. The four NEXTOR universities are connected by a common purpose—to develop and deliver research of the utmost quality and relevance. It was evident at the onset; a primary office to centralize NEXTOR's administrative

purposes was needed to provide cohesiveness and grounding for a thriving Center of Excellence.

The new centralized program office, located at UCB has increased NEXTOR's visibility through public relations by the creation of NEXTOR's web site, quarterly newsletters, and the publication and distribution of research reports. The program office's hiring of a research developer increased the functionality of its program/development and management; coordination with the FAA; and financial/contractual management. It is under the program office's auspices for the coordination of NEXTOR's biannual Steering Committee meetings and yearly research symposium.

Sponsoring Agency: FAA
NEXTOR Team: Adib Kanafani, Mark Hansen, Geoff Gosling, Scott Simcox and Norine Shima, UCB

The Role of Air Cargo in California's Goods Movement

NEXTOR carried out this project at the request of Caltrans. The goal was to gain an understanding of California's air cargo movement with respect to other modes of goods movement. The focus was on air-truck combination movement, commodity weight moved by air, commodity value moved by air, and commodity mode distribution. Researchers used the 1993 Commodity Flow Survey (CFS) to develop plausible lower and upper bounds for the first quantity type and obtained lower bounds for the last three with broad commodity categorization. Data from all categories suggests that air cargo is of greater importance for California than it is elsewhere in the nation. The project has been completed and research report RR-98-5 is available upon request in the program office.

Sponsoring Agency: Caltrans
NEXTOR Team: Jacob Tsao, Mark Hansen, Geoffrey Gosling, UCB

TASC Research on Weather Scenarios for ATM Simulations

The objective of this NEXTOR project was to develop distributed simulation techniques for the inclusion of realistic weather scenarios ATM simulations. A socket-based simulation protocol has been implemented. It now includes a distributed simulation with an enroute sector and a part task cockpit simulation. Nexrad reflectivity plots of convective weather scenarios have been integrated into the scenario. The capability of running the simulation in separate locations (TASC and MIT) has also been demonstrated. A report detailing this project, "A Distributed Simulation Facility to Support Human Factors Research in Advanced Air Transportation Technology," was presented at the Simulation Interoperability Workshop. The simulation capability was used in a study on "The Effect of Shared Information on Pilot/Controller Situation Awareness and Re-Route Negotiation" which was selected as the best paper of the 2nd USA/Europe ATM R&D Seminar.

Sponsoring Agency: TASC
NEXTOR Team: John Hansman, MIT

Traffic Flow Management for Collaborative Decision Making (CDM)

Collaborative Decision Making (CDM) achieves improved NAS performance by giving NAS users the opportunity to share information and distribute decision making to the most appropriate NAS users. Two specific tasks related to CDM are currently being addressed.

(a) Prediction of Departure Congestion and Delay

Over the past 2 years, research at MIT has been conducted on analyzing the operations at major US airports as part of an ongoing effort to (1) characterize the sources of uncertainty and delay in the airport system during departure and (2) develop an initial concept for a departure planning tool that will increase takeoff efficiency while reducing surface congestion, delays, and emissions through the improved scheduling of aircraft pushbacks and surface movements. This CDM project seeks to leverage the experience gained through the work described above in order to develop heuristic and algorithmic methodologies for predicting the departure congestion and delays at airports as a function of system operating parameters. The principals among these parameters are the expected and observed values of (1) airport configuration, (2) number of aircraft on the airport surface, and (3) number of aircraft ready or likely to be ready for pushback.

(b) Prediction of Flow-Constrained Areas for Collaborative Routing

Substantial benefits in en route airspace management can be derived through collaborative efforts to improve demand prediction and constraint identification. Through the timely dissemination of this information to NAS users, many potential instances of severe airspace congestion can be avoided by independent actions on the part of NAS users. At the same time, all problems cannot be solved by better prediction and information dissemination. In the end, there will be times when multiple airlines and independent general aviation (GA) users will be "competing" for the same saturated airspace. Such cases require resource rationing procedures similar to ration-by-schedule and compression. A queuing model has recently been developed for predicting flow-constrained areas in en route airspace. This model accepts as inputs (1) the projected flow capacity of a sector for any given set of weather conditions and available staffing and (2) the projected traffic demand. It then predicts flow constraints at the sector as measured by workload, expected number of aircraft in the sector, expected number of aircraft queued to enter the sector, and expected number of aircraft that cannot be accepted in the sector due to flow constraints. All these measures are dynamic, i.e., are provided as a function of time of the day, so that the user can identify the specific periods of the day when flow constraints are most severe, the times when flow constraints cease to exist, etc. The model is based on a dynamic queuing theory and is very fast and portable. This project involves investigation of the potential use of this model as a real-time decision-support tool for collaborative routing.

Sponsoring Agency: AOZ
NEXTOR Team: Michael Ball, UMD
Amedeo Odoni., MIT
Industry Partners: Metron

Training and Education Initiatives—Executive Leadership Workshop

a. National Airspace System Resource Allocation: Economics and Equity Workshop- *University of Maryland*

This workshop included discussion of the issues of utilization of market mechanisms, e.g., slot auctions for resource allocation and the lottery system at LaGuardia Airport and the various types and levels of NAS resources currently becoming scarce and, thus, need to be rationed. Included are the identification of present research investigations of the formal procedures used to allocate scarce resources, e.g., spectrum and electricity auctions. Workshop participants are encouraged to relate their knowledge and experience.

Sponsoring Agency: FAA
NEXTOR Team: *Michael Ball and Karla Hoffman, University of Maryland*

George Donahue, George Mason University

b. Decision Analysis Methods in Air Transportation—*Virginia Polytechnic*

This short course could be offered to complement the skills of FAA managers on the use of Multi-Criteria Decision-Making Methods (MCDM), which plays a critical role in performing our professional duties and solving many real life problems. Almost any local or federal government, industry, or business activity involves, in one way or the other, the evaluation of a set of alternatives in terms of a set of decision criteria. Generally, we need to pick up *one alternative* from a particular set of possible alternatives or, in certain cases, *all the alternatives* considered have to be *ranked*. The ranking of the alternatives is usually done according to a number of criteria that, as a rule, are *mutually conflicting*. The goal of this short course is to acquaint FAA personnel with the basic elements of the MCDM analysis, deterministic, stochastic, or fuzzy Multi Attribute Decision Making Methods, single decision maker MADM methods, and group decision making MADM. The course can be taught using appropriate tools.

c. Analysis of Air Transportation Systems- *Virginia Polytechnic*

This short course complements the skills of FAA managers to study complex air transportation systems. The course would offer three basic types of information: (1) aircraft performance and modeling issues, (2) air traffic control analysis methods, and (3) air transportation analysis techniques. This course will provide FAA managers with exposure to techniques to execute aviations systems demand and capacity analyses. This course is offered every year at Virginia Tech during the fall semester. Case studies and software uses are emphasized throughout the course.

Virginia Tech is also responsible for the organization of a master's degree program with emphasis in air transportation engineering and operations research. This program will provide qualified FAA personnel with ways to pursue MS degrees at any of the NEXTOR core universities. Virginia Tech has offered two of its programs (MS in Civil Engineering and MS in Industrial Engineering) to serve as pilot studies.

Sponsoring Agency: FAA
NEXTOR Team: Toni Trani et al., VPI

d. Performance Measurement and Analysis — *UC Berkeley*

This project was held as a workshop in aviation system performance measurement and analysis to provide FAA management with executive leadership training and education. FAA program managers had the opportunity to gain a broader understanding of how to develop and use performance metrics in the context of the ongoing FAA initiative to become a performance-based organization.

Sponsoring Agency: FAA
NEXTOR Team: Mark Hansen and Scott Simcox, UCB

Published Reports

P-97-2, “First Annual Research Symposium Proceedings,” NEXTOR, November 1997.

RR-97-1, “Preliminary Investigation of Sector Tools Descent Advisory Potential Benefits,” Seagull Technology, Inc., August 1997.

RR-97-2, “Non Standard Day Effects in ATM Trajectory Simulation,” Seagull Technology, Inc., August 1997.

RR-97-3, “Air Traffic Management Concept Baseline Definition,” Boeing Commercial Airplane Group, October 1997.

RR-97-4, “National Airspace System Stakeholder Needs,” Boeing Commercial Airplane Group, October 1997.

RR-97-5 “Modeling, Specification, and Safety Analysis of CTAS”, University of California at Berkeley, Massachusetts Institute of Technology, September 1997.

RR-97-6, “Formal Specification and Analysis of the Center-TRACON Automation System (CTAS),” Honeywell Technology Center, September 1997.

RR-97-7, “Integration of Reusable Launch Vehicles into Air Traffic Management,” Massachusetts Institute of Technology, Virginia Polytechnic Institute, November 1997.

RR-97-8, “Enhancements to SIMMOD: A Neural Network Post-processor to Estimate Aircraft Fuel Consumption,” Virginia Polytechnic Institute, December 1997.

RR-97-9, “Development of an On-site Ground Operation Model for Logan International Airport,” Massachusetts Institute of Technology, December 1997.

P-98-1, “Second Annual Research Symposium Proceedings,” NEXTOR, December 1998.

RR-98-1, “National Airspace System Operational Concept - AATT Products Mapping Analysis,” Seagull Technology, Inc., March 1998.

RR-98-3, “Airborne Based Conflict Probe,” Honeywell Technology Center, April 1998.

RR-98-4, “Preliminary Study of In-Flight Replanning Performed on the Flight Deck,” Massachusetts Institute of Technology, April 1998.

RR-98-5, “The Role of Air Cargo in California’s Goods Movement,” University of California, Berkeley, September 1998.

RR-98-7, “Air Safety - The Recent Record,” Massachusetts Institute of Technology, May 1998.

RR-98-8, “The California Aviation System: Current Status and Recent Trends,” University of California, Berkeley, December 1998.

RR-98-9, “Advanced Concepts for Collaborative Decision Making,” University of Maryland and Massachusetts Institute of Technology, March 1998.

RR-98-10, “Development of the Flight Crew Human Factors Integration Tool,” University of California, Berkeley, August 1998.

RR-98-11, “Development of the Flight Crew Human Factors Integration Tool: Implementation of Analysis Methods and Training Needs Assessments,” Embry Riddle Aeronautical University, August 1998.

RR-98-12,“Improving the Representation of Human Error in the Use of the Flight Crew Human Factors Integration Tool,” University of California, Berkeley, August 1998.

RR-98-13, “Integration of Reusable Launch Vehicles into Air Traffic Management: Phase II Final Report of MIT Research,” Massachusetts Institute of Technology, September 1998.

RR-98-14, “A Comparison of Formulations for the Single-Airport Ground Holding Problem with Banking Constraints,” University of Maryland, August 1997.

RR-98-15, “Integration of Reusable Launch Vehicles into Air Traffic Mangagement: Phase II Final Report (VPI),” Virginia Polytechnic Institute, October 1998.

RR-98-16, “Development of Airspace Sector and Encounter Models to Support the Analysis of Aircraft Separation and Collision Risk,” Virginia Polytechnic Institute, November 1998.

RR-98-17, “Empirical Analysis of Airport Capacity Enhancement Impacts: A Case Study of DFW Airport,” University of California, Berkeley, July 1998.

RR-98-18, “Multivariate Analysis of the Impacts of NAS Investments: A Case Study of a Major Capacity Expansion at Dallas-Fort Worth Airport,” University of California, Berkeley, January 1999.

T-98-1, “Models for the Stochastic Ground-Holding Problem,” Massachusetts Institute of Technology, March 1998.

T-98-2, “Integer Programming Models for Ground-Holding in Air Traffic Flow Management,” University of Maryland, December 1997.

T-98-3, “Optimization Model with Fairness Objective for Air Traffic Management,” University of Maryland, September 1998.

WP-98-1, “Airline Delay Perturbation Problem Under Minor Disturbance,” University of California, Berkeley, June 1998.

WP-98-2, “Proposed Functional Enhancements for the Flight Crew Human Factors Integration Tool,” University of California, Berkeley, August 1998.

WP-98-3, “Development of System Safety Performance Measures in Support of the Global Analysis and Information Network,” University of California, Berkeley, August 1998.

P-99-1, “NEXTOR Research Presentations at Steering Committee Meeting,” NEXTOR, June 1999.

P-99-2,“Third Annual Research Symposium Proceedings,” NEXTOR, November 1999.

RR-99-1, “The Static Stochastic Ground Holding Problem with Aggregate Demands,” University of Maryland, January 1999.

RR-99-3, “Collaborative Decision Making in Air Traffic Management: A Preliminary Assessment,” University of Maryland, August 1998.

RR-99-4, “Integration of Reusable Launch Vehicles into Air Traffic Management: Phase III Final Report,” Virginia Polytechnic University, June 1999.

RR-99-5, “Integration of Reusable Launch Vehicles into Air Traffic Management: Phase III Final Report,” Massachusetts Institute of Technology, July 1999.

RR-99-6, “An Investigation on the Integration of NAS Models,” Virginia Polytechnic University, October 1999.

RR-99-8, “ Development of Fast-Time Simulation Techniques to Model Safety Issues in the National Airspace System,” University of California, Berkeley, December 1999.

WP-99-1, “Aviation System Performance Measures,” University of California, Berkeley, January 1999.

WP-99-2, “A Five-Year Development Plan for the California Aviation Database,” University of California, Berkeley, June 1999.

WP-99-3 , “The Role of Intelligent Transportation Systems in Intermodal Air Cargo Operations,” University of California, Berkeley, October 2000.

PP-00-1, “Fourth Annual Research Symposium Proceedings,” NEXTOR November 2000

RR-01-1, “Use of Next-Generation Satellite Systems for Aeronautical Communications: Research Issues,” Virginia Polytechnic Institute, February 2001.

RR-01-2, “Influence of Capacity Constraints on Airline Fleet Mix,” Institute of Transportation Studies, University of California at Berkeley, August 2001.

RR-01-3, “Delay and Flight Time Normalization Procedures for Major Airports: LAX Case Study,” Institute of Transportation Studies, University of California at Berkeley, June 2001.

RR-01-4,“Development of Fast-Time Simulation Techniques to model Safety Issues in the National Airspace System,” ATAC Corporation, Massachusetts Institute of Technology and University of California at Berkeley, November 12, 2001.

RR-01-5, “Optimization and Mediated Bartering Models for Ground Delay Programs,” Robert H. Smith School of Business and Iinstitute for Systems Research, University of Maryland, August 23, 2001.

RR-01-6, “Delivering Real-Time Weather Maps to Aircraft by Hybrid Uni-cast/Broadcast LEO/GEO Satellite Communications,” Institute for Systems Research, Department of Electrical Engineering, Univeristy of Maryland.

RR-02-1, “Assessing URET Benefits for Airspace Users: A Quasi-Experimental Approach,” Institute of Transportation Studies, University of California at Berkeley, April 2002.

RR-00-2, “Research Issues and Conflict Analysis of Air and Space Modes of Transportation,” Massachusetts Institute of Technology, June 2000.

RR-00-3, “Measuring Ground Delay Program Effectiveness Using the Rate Control Index,” University of Maryland, June 2000.

RR-00-4, “The Rate Control Index for Traffic Flow,” University of Maryland, January 2000.

RR-00-5, “Technology Refreshment Cost Estimating and Planning Model: User's Guide,” Logistics Management Institute, June 2000.

RR-00-6, “An Analytic Study of the Benefits of Collaborative Arrival Planning on Air Carrier Ground Operations,” Draper Laboratory, May 2000.

RR-00-7, “A Preliminary Design Process for Airspace Systems,” Boeing Company, October 2000.

T-00-1, “Increasing Airline Operational Control in a Constrained Air Traffic System,” University of California, September 2000.

WP-00-1, “An Analysis of Air Passenger Average Trip Lengths and Fare Levels in US Domestic Markets,” University of California, Berkeley, February 2000.

WP-01-1, “Factors Influencing Blind Collision Risk in En Route Sectors Under Free-Flight Conditions,” University of Maryland/Rensselaer Polytechnic Institute, May 2001.

WP-01-2, “Estimating Components of Variation in Flight Times,” University of Maryland/Rensselaer Polytechnic Institute, May 2001.

WP-01-3, “Contingencies and Cancellations in Ground Delay Programs,” Rensselaer Polytechnic Institute, May 2001.

WP-01-4, “Analytical and Empirical Analyses of the Impacts of Restricting Airspace” Massachusetts Institute of Technology, December 31, 2001

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Information Dissemination:

Updated by Francisco Estrada C. FAA NEXTOR Program Manager 4/26/04

Education/Training: Offered to the FAA and aviation community NEXTOR member at least three times per year. Each university sponsors a training seminar/short course. Since 2003, more than 100+ FAA employees, industry partners and contractors have taken short courses offered by NEXTOR. Recent courses include:

"Optimization/Heuristics Techniques in Air Transportation," June 1-3, 2004, (VPI)

"The Airline Industry Management & Decision Making," July 23-24, 2003 (MIT)

"Analysis of Air Transportation Systems," June 9-12, 2003 (VPI)

"Equity and Fair Resource Allocation in Air Traffic Management," May 12-5, 2003 (UMD)

Conferences & Workshops: Knowledge transfer id conducted thorough conferences and workshops. In the last 2 years NEXTOR has conducted the following conferences/workshops. These have all been well attended by FAA, contractors, and industry members of NEXTOR:

1St Symposium on Air Transportation and Regional Social and Economic Development, April 1-2nd, 2004, (MIT)

Moving Metrics: A performance-Oriented View of the Aviation Infrastructure, January 27-30, 2004 (UCB)

Air Traffic Management and Control, June 2-4, 2003 (VPI)

Performance Metrics Workshop, November 20-33,2003 (UCB)

NAS Capacity and the Environment, August 28, 2002 (MIT)

NAS Resource Allocation: Economics and Equity, March 19-20, 2002 (GMU/UMD)

Centers of Excellence

Airworthiness Assurance

Established September 1997

The Federal Aviation Administration (FAA) established an Aviation Research Center of Excellence (COE) in the technology area of Airworthiness Assurance in 1997. AACE is a multi-institutional, multi-disciplinary team established by the FAA to address research, development, education, and technology transfer in the area of airworthiness assurance. AACE's mission is to contribute significantly toward aviation accident rate reduction, especially in fatalities, thus improving aviation safety.

In today's competitive market, the FAA realizes that the best way to investigate and resolve aviation safety issues is to build a research team that combines the best talent from government, academia, and private industry.

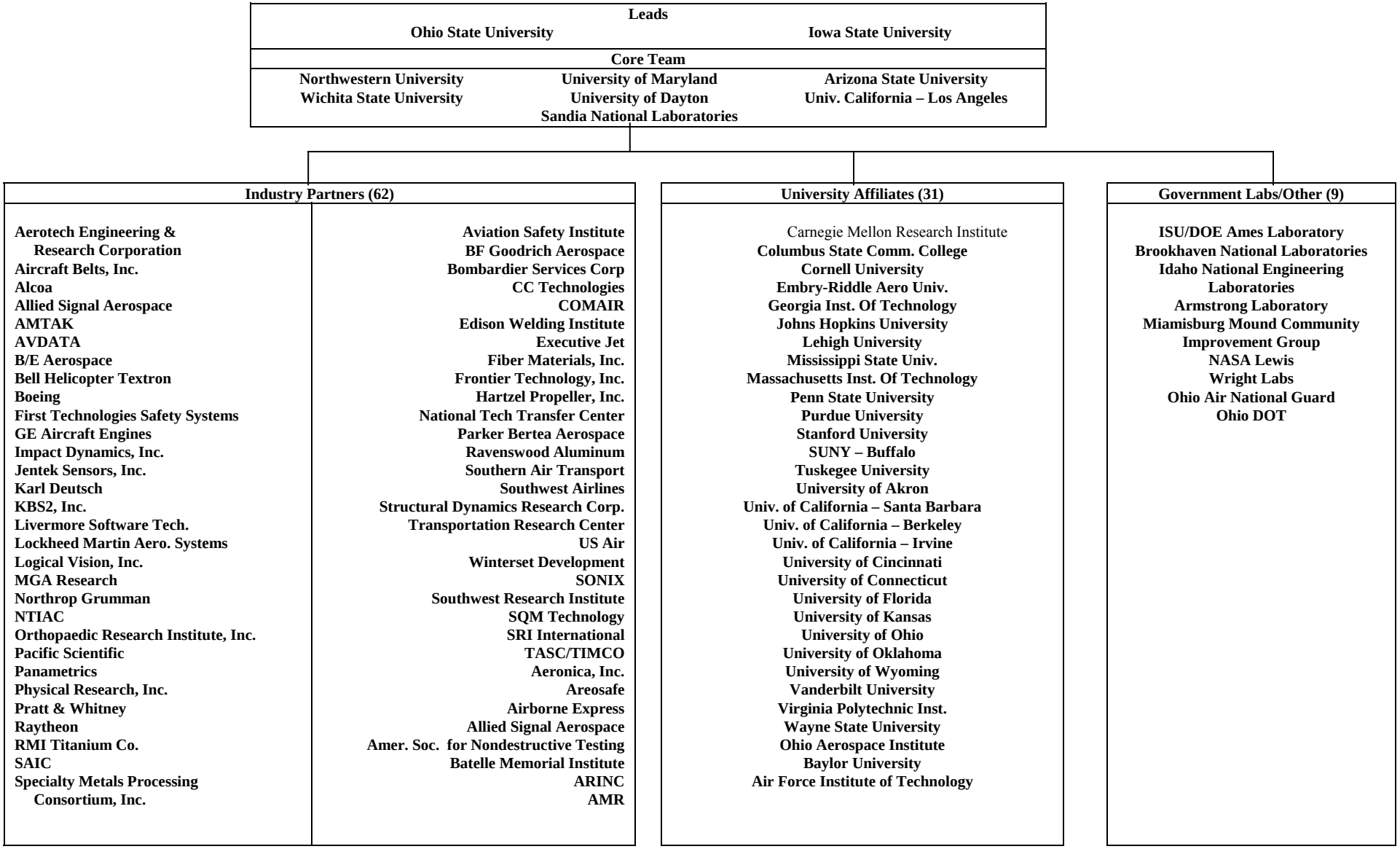
AACE researchers provide technical support and engineering data to many of the key industry committees that deal with industry standards and specifications and define methods and processes used in the manufacture, operation, maintenance, repair, and inspection of aviation products.

With the active participation of private industry, AACE has experts from over 50 of the pre-eminent companies in the aviation industry such as Boeing, Lockheed Martin, Raytheon Aircraft, General Electric, Pratt & Whitney, and American Airlines partnering to improve aviation safety.

Sponsoring Organization: Airport and Aircraft Safety R&D Division

FAA COE PM: Jim White

Center of Excellence in Airworthiness Assurance Organization – Phase I



Center of Excellence in Airworthiness Assurance
University Partners – Phase II

Arizona State University	Sandia National Laboratories
Baylor University	The Ohio State University
Carnegie Mellon University	The University of Arizona
Embry-Riddle Aeronautical University	Tuskegee University
Iowa State University	University of California-Berkeley
Johns Hopkins University	University of California-Los Angeles
Lehigh University	University of California-Santa Barbara
Mississippi State University	University of Dayton
New Jersey Institute of Technology	University of Maryland
North Carolina A&T State University	University of Missouri-Columbia
Northwestern University	University of North Dakota
Ohio University	University of Utah
Pennsylvania State University	Wayne State University
Purdue University	Wichita State University
Rutgers, The State University of New Jersey	

Projects

Survey of Aviation Maintenance Technical Documentation

Until recently, little attention has been paid to the procedures used to develop and revise aircraft maintenance technical data. Studies of maintenance errors have tended to focus on the actions of the mechanic, job culture, and work procedures. More recently, attempts have been made to document the source of maintenance errors and improve maintenance procedures. One of the identified contributing causes of errors is the documentation used to guide maintenance tasks. As a result, efforts have been made to establish guidelines for the design of maintenance job aids. A question that remains is how the procedures used by manufacturers to develop maintenance data may contribute to user error. This research project is a three-phase research effort designed to examine (1) the procedures used by industry to develop maintenance manuals, (2) document the problems encountered by users of these documents, and (3) identify ways in which human factors principles can be used to improve the development of these documents.

Alex Chaparro, Ph.D., Wichita State University

Simulation and Flight Test Assessment of Safety Benefits and Certification Aspects of Advanced Flight Control Systems

One of the NASA AGATE tasks being investigated by the general aviation (GA) community, in particular a task addressed by Raytheon Aircraft, is a simplified flight control system coupled with advanced cockpit displays and pilot aids. This system, by necessity, is a computerized fly by wire, flight-critical system that has to be tolerant of in-flight sensor and/or actuator failure. The cost of adapting existing systems (used in commercial aviation) to GA use is currently prohibitive. This project is investigating the safety and reliability enhancements that nonlinear adaptive control can bring to GA aircraft. These nonlinear adaptive controllers can maintain acceptable flying qualities of an aircraft after the onset of a failure. Simulations showing acceptable adaptation of the control system to various failure modes in a GA aircraft under realistic flight conditions followed by flight tests in the Raytheon Aircraft Fly By Wire testbed research Bonanza aircraft will be used to assess the safety and reliability benefits and certification issues that these advanced control systems will bring.

James E. Steck, Wichita State University
Kamran Rokhsaz, Wichita State University
Urpo J. Pesonen, Wichita State University
Ilaiyarasan Elangovan, Wichita State University

Noel Duerksen, Raytheon Aircraft
Sam Bruner, Raytheon Aircraft

Explicit Finite Element Analysis Modeling of Multi-Layer Composite Fabrics for Gas Turbine Engine Containment Systems

The objective of this research is to develop a robust explicit finite element analysis methodology for the purpose of designing a turbine engine rotor containment system. This task will collaborate the technical strength of the team members to accomplish this objective. In addition, this task will explore the potential of Zylon fabric material for advanced turbine engine containment application. By using the results of previous work sponsored by the FAA in fabric barriers/modeling, and NASA engine containment ballistic test facility to verify the model, this task will be able to transfer research technology to practical use in an engine containment system.

Prof. S. Rajan, PI, Arizona State University
Shen-Yeh Chen, Honeywell Engines
Don Shockey, SRI International
Mike Pereira, NASA-Glenn
FAA Monitor: Don Altobelli, AAR-460

Lightweight Ballistic Protection of Flight-Critical Components on Commercial Aircraft

The objective of this research is to evaluate the applicability of Zylon fabric to protect flight-critical aircraft components from fragments resulting from an uncontained engine failure. This task will verify and improve LS-DYNA3D Zylon design tool developed under previous work sponsored by the FAA through analysis of ballistic tests. The research plan also includes measurement and verification of mechanical and environmental properties of Zylon to determine aircraft operation compatibility.

Prof. W. Goldsmith, PI, UC Berkeley
Jerry Farstad, Boeing
Don Shockey, SRI International
FAA Monitor: Don Altobelli, AAR-432

Flight Critical Data Integrity Assurance for Ground-based COTS Components

This project investigates the issues of making the Commercial-Off-The-Shelf (COTS) ground-processing system for aircraft maintenance trustworthy and secure. The research will be carried out in three directions: information and data protection, access security and safety-critical aspects of COTS ground systems. The research approach is two fold. (1) to study the application of data protection and authentication approaches in other industries, such as e-Business, and identify their limitations and strengths, and (2) to identify safety requirements and appropriate processes and objectives associated with data integrity in COTS-based ground systems for existing maintenance procedures and future condition-based management in Health and Usage Monitoring System (HUMS).

Yann-Hang Lee, and Jim Krodel, Arizona State University
Jim Krodel, United Technologies Research Center

Additional worker: William Weiss
Graduate assistants:
Jimmy John, Amit Deshmukh, and Vikram Phadke

Safety and Certification Approaches for Ethernet-based Aviation Databuses

This project is an investigation into the safety and certification issues of Ethernet-based aviation databuses. There are significant technical hurdles that must be overcome before Ethernet will be a viable candidate as an aviation databus. Through test experiments and model analyses, we expect to gain an improved understanding of the potential safety issues and to provide enlightened guidance relative to network structures and operations as they relate to meeting the applicable safety requirements. Collaborative relationships with standards, working groups, the aerospace industry, and regulatory agencies will be established. Through this process, the relevant concerns can be discussed and addressed, and an industrywide effort to define a safe Ethernet-based aviation databus can be initiated.

Yann-Hang Lee, and Elliott Rachlin, Arizona State University
Elliott Rachlin, Honeywell Laboratories
Additional worker" Philip Scandura, DER
Graduate assistants: Daeyoung Kim and Deming Liu

Design and Automation of Requirements Management Process for the System Approach for Safety Oversight

The general goal of this project is to design and automate a process that will oversee and coordinate requirement changes among all entities under the System Approach for Safety Oversight (SASO) umbrella. SASO is an FAA Flight Standards Organization (AFS) initiative that is trying to improve aviation safety based on the system approach principle. As such, SASO will cover several other AFS safety initiatives being developed and/or implemented by different AFS organizations. Each of these entities may (or may not) has its own requirements change management (RCM) process. A requirement change request approved by one entity may affect other entities. Due to the lack of a proper interface between these entities, the effect of that change from one entity on other entities is not properly analyzed or recorded. Thus, the overall safety performance of the whole system can be compromised. The objective of this research is to develop and propose a consistent higher-level interface to assist different AFS entities to manage and track the changes of their requirements. The research also focuses on technologies and techniques that help automate the process and minimize the negative effect in requirements changes among AFS entities.

H. Cheraghi and J. Hutchinson
FAA Monitor: M. Vu

The Evaluation of Cold Dwell Fatigue in Ti-6242
The Ohio State University

J. Blank, Masters, Materials Science and Engineering
J. Tatalovich, Masters, Materials Science and Engineering
D. Norfleet, BS, Materials Science and Engineering
Deepu Sebastian Joseph, Ph.D. student, Mechanical Engineering
Vikas Hasija, M.S. student, Mechanical Engineering

Real-Time Scheduling Analysis

The purpose of this task is threefold. (1) To study the need and significance of real-time scheduling in the avionics industry, (2), to survey the current practice in the avionics industry in dealing with real-time scheduling. In particular, how current systems schedule real-time tasks, how feasibility is validated, how fault-tolerant the system is, etc., and (3) to extend the Deadline Monotonic scheduling algorithm developed by the Principle Investigator and Jennifer Whitehead to include (a) systems with possible system faults, (b) systems with limited interrupt levels, (c) systems with multiple processors, and (d) systems with I/O activities integrated into CPU scheduling.

Dr. Joseph Leung, P.I. New Jersey Institute of Technology
Ms. Hairong Zhao, Graduate assistant

Mr. Chuck Bergen, WOW-IS

Assessment of Software Development Tools for Safety Critical Real-Time Systems

The main objective of this research is to identify the assessment criteria to allow both the developer and the certifying authority to evaluate the specific real-time software development tool from the system/software safety perspective. The related objectives are to present and assess the state of art in safety critical software development tools and generate a set of guidelines for the tool selection. The intended audience includes program/procurement managers, project leaders, and system/software engineers directly involved in implementing real-time safety-critical systems. The research requires close industry cooperation and the results will be propagated over the Internet.

Dr. Andrew J. Kornecki, P.I., Embry-Riddle Aeronautical University
Graduate Assistants: Jean-Phillippe Linardon and Jonathan Labbe
Affiliated Faculty: Dr. David Gluch, Embry-Riddle Aeronautical University
Mr. Nick Brixius, Embry-Riddle Aeronautical University
Dr. Janusz Zalewski, University of Central Florida

Data and Methodologies for Structural-Life Evaluation of Small Airplanes

The purpose of this project is to support the revision of AC 23-13 (Fatigue and Fail-Safe Evaluation of Flight Structure and Pressurized Cabin for Part 23 Airplanes) by adding new airplane usage data, guidance on mission profiles/mixes, new material properties data, and developing a methodology for structural-life evaluation based on the newly acquired information. AC 23-13 currently references AFS-120-73-2 (Fatigue Evaluation of Wing and Associated Structure on Small Airplanes), which will be superseded by the revised AC 23-13. The original AFS-120-73-2, published in 1973, requires new information to reflect new airplane usage data and new material properties data. The data and results from this research will be included in the revision of AC 23-13. This will result in one single advisory document that contains all current fatigue substantiation methods. A single document will provide clearer guidance in the area of fatigue substantiation and will eliminate referencing AFS-120-73-2 from AC 23-13. The new information obtained from this research will enable the continued evaluation of structural health for the aging general aviation fleet.

Dr. James Locke, PI
Research Associate: Brijesh Kumar
Graduate Student: Ivan Contreras
FAA COTR: Dr. Michael Shiao

Generation and Detection of Fatigue Cracks Near Rivets

The nondestructive study of short fatigue cracks in riveted lap joints is difficult because the cracks originate on or near hidden surfaces and grow to a number of microns in radius before being visible on the outside surface. In the present study, the scanning acoustic microscope was used to quantitatively investigate subsurface fatigue cracks at and near countersunk rivets in riveted lap joint specimens even before and just after they reached an outside surface. Optical and electron microscopic examination of the surface and fractography of fractured specimens combined with scanning acoustic microscope examination characterized, in detail, the formation and growth of subsurface cracks near rivets. The specimens were fabricated from two panels of Alclad 2024-T3 aluminum alloy riveted with 2017-T4 aluminum alloy flathead chamfered rivets. Additionally, tests were run to compare the two materials, Alclad 2024-T3 and 2524-T3. The fatigue testing was interrupted periodically for examination and some specimens with just detectable and larger subsurface cracks were fractured in tension to reveal the fatigue fracture surfaces for analysis. A detailed study of crack formation and microcrack growth kinetics near such rivets is presented, including the location of the initiation sites as affected by applied load. Preliminary studies were performed on specimens of A356 Al alloy to determine the usefulness of the scanning acoustic microscope to study subsurface defects in a cast alloy.

Morris Fine – Northwestern University

Student Intern Program for Emerging NDI Techniques

Lewis University operates a large NDI training program at Moraine Valley Community

College, about 35 miles southwest of downtown Chicago. The staff of the NDI training program consists of both full-time and part-time instructors who have had significant field experience in the performance of NDI. The Lewis University program provides personnel with strong undergraduate NDI training.
Northwestern University is cooperating with Lewis University/Morraine College to train interns in emerging techniques for nondestructive inspection of aircraft. The Lewis University undergraduate program and the graduate NDI program at Northwestern University form a balanced program of instruction and research and development in nondestructive evaluation. Students and faculty of Lewis University are invited to participate in the research, development validation, and technology transfer carried out at Northwestern University. In this manner, future NDI engineers have an early exposure to advanced techniques when these techniques are still in the developmental stage. Conversely the program at Northwestern University benefits from the input from undergraduate students who are well trained in the techniques of nondestructive testing. An NDI workforce that has been exposed to a broad spectrum of NDI techniques benefits the FAA, the aircraft industry, maintenance facilities, and the airlines.

Investigator: Sridhar Krishnaswamy, Northwestern University

Design and Quality Assurance of Premium Quality Airframe Castings

Increased use of castings is being given consideration by both airframe and engine manufacturers. Advantages of cast structures over the conventional built up structure are many including the following:

- Reduced part count
- Part–to–part dimensional consistency
- High structural reliability
- Improved serviceability
- Lower procurement cost and replacement cost
- Reduced system complexity with repair and maintenance safety benefits

To implement new cast components, their capability to carry design loads in the presence of damage before catastrophic failure (or prior to the next inspection interval) must be understood. An integrated approach to design that takes into consideration defect formation (type/location per casting process parameters), crack formation/growth and residual strength, and inspectability is the focus of this program.

Investigators: J. Gray, F. Inanc, and T. Jensen, Iowa State University
Industry partners: Boeing, Hitchcock, Pratt & Whitney, Cercast, Howmet, PCC Structurals

NDE Technologies Assessment and Infrastructure Support

This project provides technical support to the FAA-CASR, ETC, and AANC programs. The principal investigator works with the staff of each of these programs, the FAA, and industry in solution of short-term projects and provision of samples. Short-term projects are brought to the attention of the CASR staff through interactions with the FAA directorates, William J. Hughes Technical Center staff, FAA NDE-NRS, and industry. This has included such topics as visual inspection of cracks under decals, evaluation of crankshaft inspection procedures, development of inspection procedure for Piper wing lift strut, and evaluation of samples with magnetic particle and other techniques. This approach involves three steps:

- Determine the appropriate NDE technique based on the requirements
- Acquire the test samples and develop the inspection technique
- Demonstrate and document the results

The staff also supports the FAA on technology-based issues such as the assessment and stabilization of fluorescent penetrant inspection (FPI) in the aviation industry. This included interactions with the FAA, Air Force Wright Laboratory, and industry members to identify the work necessary to transport the current capability related to FPI to the technology base. The steps included an assessment of current practices through a literature search, which has been submitted as an FAA Technical Report. Copies have been distributed among members of SAE Committee K – Nondestructive Evaluation. Sample preparation processes used to produce additional cracked panels for FAA and Air Force use in FPI evaluation have been developed and documented. In 1999, the industry requested that the literature be surveyed to summarize engineering data available for magnetic particle inspection. In addition to this report, a computer tool that allows assessment of magnetic particle through simulation is under development. The first version code was demonstrated at the 2000 ATA NDT Forum.

Investigators: Brian Larson, Rick Lopez, and Lalita Upda, Iowa State University
Industry partners: UAL, NWA, Delta, Boeing, PW, Allison/Rolls Royce, GE, Honeywell

Aging Characterization and Lifetime Assessment of Polymeric Insulation in Aircraft Wiring

Examination of the problem of aging electric wire insulation is under way to determine the best methods to routinely characterize insulation integrity in existing aircraft as well as to provide insight as to how health monitoring could be installed as an integral component of new aircraft. The work consists primarily of the development of an impedance spectroscopy technique that could be used as an *in situ* test method for intact wiring. This work is being supplemented by standard characterization methods, such as Fourier transform infrared spectroscopy (FTIR), optical microscopy and scanning electron microscopy. Both naturally aged and laboratory-aged wires are being evaluated. Identification of the primary aging mechanisms as well as suitable nondestructive testing techniques are under way. Results of the research effort will help define the impact of aging factors on wire insulation and provide tools to predict and detect critical degradation levels.

Investigators: L. C. Brinson, S. Carr, T. Mason, and K. Shull, Northwestern University
Industry partners: Boeing, Sandia, and Belden Wire Company

Thermal Wave Imaging Technology Transfer

Goals/Objectives:

Advances made by Wayne State University in their thermography system made this technology the leading candidate for technology transfer as part of the AANC mission. This effort focused on two projects: (1) solving the problems associated with the quantification of corrosion on the backside of a painted surface and (2) transferring the technology to a composite manufacturing/repair station for use in certification of newly manufactured parts and composite repairs. This project included participation frin Boeing Commercial Airplane Company, Northwest Airlines (project 1), and The Nordam Group (project 2).

Investigators: Mike Ashbaugh, Sandia National Laboratories, Bob Thomas, L.D. Lawrence, and X. Han, Wayne State University

Applications of Computational Reliability Analysis-(XRSIM)

A powerful tool for x-ray optimization, known as XRSIM, has been developed at Iowa State University (ISU) and beta tested with numerous industry partners. The tool generates simulated radiographs based on input from the user, which include parameters for the generator, the detector, the component and the flaw of interest. Capability exists for CAD input of both the component and the flaw morphology. Typical detectors used in industrial radiography and typical generator performance characteristics are selectable by the user. Ability to add generators or detectors of interest to the user also exists. The user is able to determine minimum detectable flaw size as a function of position in the component, assessing coverage and Probability of Detection (POD). The ability to generate POD maps and transition of the code to a PC environment have been the major accomplishments during this task.

Investigators: Joe Gray, J. Xu, and F. Innac Iowa State University
Industry partners: Boeing, PW, Allison/Rolls Royce, GE, Honeywell, UAL, and NWA

Understanding of Anisotropic Effects on Inspectability of Aerospace Materials

While rotating components have received the primary focus from the life management community, both at the original equipment manufacturers (OEMs) and the FAA, airline maintenance personnel also place considerable emphasis on the need for inspection tools for static parts. In CAAM reports, 31 case ruptures were reported with 6 of those being category 3 and 4 events. Communications with New England Directorate certification staff and engineers at P&W support the need for efforts in this area. Static parts offer particular challenges to inspection because of their intrinsic material properties and weld effects. Grain diffraction effects cause considerable difficulty in the evaluation of radiographic images at production and in-service inspection of cast components such as static parts, blades, and structural airframe components. Welds exist in most static

components, either as repairs or in attachments of flanges, bosses, and other geometric features. Anisotropy effects cause concern for ultrasonic and radiographic inspection. This task was limited to radiography applications. In radiography, grain diffraction effects from nominal microstructure can lead to film mottling, which can mask the response from a defect. This task sought to understand this phenomena and develop techniques to improve the signal to noise ratio.

Investigators: Joe Gray and S. Wendt, Iowa State University
Industry partners: Boeing, PW, and UAL

Optimized Ultrasonic Techniques for Multilayer Structures

Goals/Objectives:

Past efforts at Northwestern University lead to successful ultrasonic inspection of DC-9 wingbox structures. A dual-probe inspection was developed for the multiple-layered structure, which replaced an 800-hour visual inspection procedure with a 48-hour ultrasonic inspection. Safety enhancements resulted from improved reliability complimented by cost savings of millions to the industry. A cooperative program that teamed the researchers at Northwestern with AANC staff, Northwest Airline personnel and OEM inspection and structures engineers led to AMOC approval by the FAA Los Angeles ACO. The technique has been used by Northwest, Delta, and USAir as well as transferred to military applications.

Building on this success, the current project continued development and application of the ultrasonic techniques for detection, characterization, and sizing of defects in second and third layers of multilayered aircraft structures. A method for the systematic selection of ultrasonic wave modes and transducer configurations, based on the spatial orientation of layers, fasteners, and flaws, is under development. These parameters must be selected correctly for optimal penetration into the structure and optimal reception of reflected, transmitted, diffracted, or scattered ultrasonic signals. Procedures to determine an optimal measurement model, including considerations for the spatial orientation and sizes of structural elements (fastener holes) and defects (cracks), are under development. Several applications have been defined by industry partners. Both crack detection and sealant integrity are issues in development of the inspection. Technique development occurs as part of this task. Implementation using commercially available instrumentation is performed under a separate delivery order, “A Modular Imaging System for Ultrasonic Inspection.”

Investigators: Igor Komsky, Jan Achenbach – Northwestern University
Industry partners: Boeing (Seattle), Boeing (Long Beach), Northwest Airlines, Cessna

A Modular Imaging System for Ultrasonic Inspection

A modular inspection system for use in a variety of ultrasonic testing procedures has been developed. The system integrates commercially available and newly developed scanning modules with commercially available data acquisition modules and/or conventional portable ultrasonic flaw detectors. The data is acquired and transferred for imaging, using software modules optimized for the specific configuration of an airplane structure, the type of flaw, and the type of ultrasonic equipment typical in an airline facility. The system will be capable of detection, characterization, and imaging of fatigue cracks and corrosion in second and third layers of multilayered airplane structures, from outside surfaces, without disassembly. For corrosion inspection, a complete map of material loss and/or residual thicknesses of the internal layers can be generated. For crack inspection, an image of the crack is displayed with complete information on crack size, location, orientation, and shape. The inspection system can be deployed on surfaces with limited and/or obstructed access, such as surfaces with protruding fasteners, channels, doublers, and angles. Hardware and software development is accomplished as part of this project. A companion project, "Optimized Ultrasonic Techniques for Multilayer Structures", provides technique development support.

Investigators: Igor Komsky and Jan Achenbach, Northwestern University
Industry partners: Panametrics, Krautkramer-Branson, Foerster, QMI, Boeing (Seattle), Boeing (Long Beach), and Northwest Airlines

Liquid Penetrant Technology Support Continuation

The FAA requested that the Airworthiness Assurance NDI Validation Center (AANC) establish an on-site capability that evaluates liquid penetrant inspection capabilities that responds to changing requirements in both the military and commercial sectors. Recommendations from the penetrant technical community included the request that AANC develop and fabricate test specimens that are repeatable and reliable when evaluating penetrant materials. The intent of this project is to provide access to crack qualification standards, which allow penetrant manufacturers and aircraft industry end-users to develop a better understanding of the fundamental-governing chemical and physical mechanisms of the liquid penetrant inspection process. Updates of task progress are provided annually to the ASNT MT/PT Committee.

In cooperation with CASR staff, five sets of six samples were produced with crack lengths from 0.76 to 1.27mm and an aspect ratio of 2 to 1 using Ti-6Al-4V. AANC is currently characterizing low-cycle fatigue specimens that will support the needs of penetrant manufacturers, commercial airline industry, and the FAA. The main focus of this characterization is to maintain and enhance the evaluation of penetrant inspection materials and apply resources to support the aircraft community needs. Characterization included scanning electron microscopy work performed at CASR as well as brightness studies performed at AANC.

Investigators: David Moore, Sandia National Laboratories
Industry partners: ASNT penetrant committee and Air Force Materials Labs

Validation of Composite Repairs on Metallic Aircraft Structures

Economic barriers to the purchase of new aircraft have created an aging aircraft fleet and placed even greater demands on efficient and safe repair methods. The use of bonded composite doublers offers the airframe manufacturers and airline maintenance facilities a cost-effective technique to safely extend the lives of their aircraft. Instead of riveting multiple steel or aluminum plates to facilitate an aircraft repair, it is now possible to bond a single Boron-Epoxy composite doubler to the damaged structure. However, before this advanced aircraft repair technique could be accepted for commercial aircraft use, uncertainties surrounding the application, subsequent inspection, and long-term endurance of composite doublers had to be addressed. This validation project is intended to introduce and properly control the use of composite doubler technology on commercial aircraft. It identified the necessary FAA guidance to assure the continued airworthiness of composite doublers. This project focused on a family of commercial aircraft repairs and encompassed all cradle-to-grave tasks to evaluate the viability of composite doublers.

Investigators: Dennis Roach, Sandia National Laboratories
Industry partners: Boeing, Federal Express, Delta Air Lines, American Airlines, and Textron

Development of Composite Reference Standards

The rapidly increasing use of composites on commercial airplanes coupled with the potential for economic savings associated with their use in aircraft structures means that the demand for composite materials technology will continue to increase. The FAA recognizes the need to produce guidance that will assure the airworthiness of composite structures. The Commercial Aircraft Composite Repair Committee (CACRC) Inspection Task Group identified a need for a set of "generic" composite reference standards for use by operators in setting up their inspection equipment. CACRC personnel solicited the AANC's participation in this effort because it was felt that the AANC could develop and evaluate the standards in an independent manner that is attentive to the needs of all aircraft designs.

In this project, the AANC conducted a series of NDI tests on a matrix of composite reference standard prototypes in order to minimize the number of standards needed to carry out composite inspections on aircraft. The standards and accompanying NDI tests also enabled improvement and optimization of composite inspection procedures. The project tasks addressed both composite laminates and composite honeycomb configurations. Composite laminate and honeycomb samples were produced and evaluated. A standard set has been agreed upon by the CACRC for use in calibrating inspection equipment with the description to be published as an SAE Aerospace Recommended Practice.

Investigators: Dennis Roach, Kirk Rackow, and Larry Dorrell, Sandia National Laboratories
Industry partners: Boeing, Airbus, British Aerospace, Northwest Airlines, US Airways, United Airlines, Air Canada, and CACRC

Rotorcraft Validation and NDI Assessment

Increasing niche applications, growing international markets, and the emergence of advanced rotorcraft technology are expected to greatly increase the population of helicopters over the next decade. In terms of fuselage fatigue, helicopters show similar trends as fixed-wing aircraft. The highly unsteady loads experienced by rotating wings not only directly effect components in the dynamics systems but are also transferred to the fixed airframe system.
Until recently, the safe-life fatigue design approach was the dominant method for designing and maintaining rotorcraft dynamic and airframe components. The safe-life maintenance practice involves retiring components before crack initiation. Because the predicted safe-life theories are reliability-based, the predicted crack initiation times can be extremely conservative. As a result, maintenance practices for helicopters can be costly and involve large amounts of spare parts. Consequently, there is a need for an alternative maintenance strategy that can provide lower life-cycle cost and ensure safety against unexpected failures, namely damage tolerance and associated NDI. Fatigue failures in flight-critical structures have necessitated a number of in-field inspections based on DTA and efforts are under way to support widespread application of damage tolerance to the maintenance of aging rotorcraft structures.

Investigators: Dennis Roach, Kirk Rackow, and Larry Dorrell, Sandia National Laboratories
Industry partners: Bell Helicopter, Sikorsky, Petroleum Helicopters. Inc., U.S. Navy, and U.S. Army

Modeling Optimization Tools for MOI Technology

Magneto-optic eddy-current imaging (MOI) systems have shown considerable promise in detecting corrosion and second-layer cracking. A major advantage of this inspection method is the large area coverage and easy-to-interpret images produced by the MOI systems. Most of the research efforts for this technique have focused on development of improved supporting hardware and electronics. However, more work needs to be done in the area of improving the MOI film sensors. The more sensitive the sensor, the greater the probability of detection of a critical flaw.

For overall design optimization of the system it is essential to know the absolute magnitude value of the magnetic field produced by a defect or corrosion located deep within the sample. Crucial for such studies is the development of a numerical model for simulating the underlying physical process. The availability of a mathematical model provides a better understanding of the physics, which in turn helps in making more informed design decisions. Currently, images obtained with thick single-layer samples vary significantly from those obtained with thinner multilayer samples. The quantitative effect of the air gaps between layers on the resulting images was not well understood. The model developed in this program serves as an experimental test bed for carrying out parametric studies that are too expensive to perform experimentally. The model allows the characterization of magnetic flux density for a given test situation under varying experimental conditions such as bias fields, frequency, excitation level, induction foil thickness, and defect parameters. The prediction of magnetic fields can be used in

optimizing the imaging process. Initial work on adapting an existing finite element (FE) model for MOI geometry has been completed and the fields due to calibration defect have been computed, comparing it with experimental measurements validated the predicted field. The MOI work has been funded under two separate contracts.

Investigators: Lalita Udpa, Iowa State University
Industry partners: PRI Inc. and Boeing

Contact Transducer Optimization for Inspection

During the design process, any known inspection requirements are usually "designed out" of the component to reduce downtime and operation costs. Therefore, most engine and airframe components with in-service inspection reliability issues are the result of unexpected durability conditions and require a rapid inspection development and implementation. Ultrasonic inspections in a maintenance environment are frequently performed using contact transducers and wedges because of the need for rapid inspection turnaround and the desire to perform the inspection in situ. Reliability of these inspections is complicated by the need to test components with complex geometrical shapes, made from various materials, and possessing different surface finishes. Examples of these components include lug features, bolts, tie rods, fuse pins, static cases, propellers, fan blades, rotating and nonrotating engine components, etc.

This program is developing analytical, model-based software tools that compute inspection reliability of contact ultrasonic measurements applied to engine and airframe components. Representative geometrical, material, and surface features are being selected in cooperation with industry partners. Current inspection approaches and their limitations will be identified in cooperation with partners Boeing and PW. Ultrasonic measurement models for contact inspection are being developed, with model validation occurring, largely, at the OEM sites. These models will extend and complement other software tools that have been developed for immersion UT inspection, in part, in the FAA-funded Engine Titanium Consortium.

Investigators: Tim Gray and Mike Garton, Iowa State University
Industry partners: Boeing, and PW

Signal Classification Tools for Aviation Applications

Automatic signal classification systems are becoming increasingly popular in a number of commercial applications largely due to their ability to provide accurate and consistent interpretation of nondestructive inspection signals. Moreover, the advent of PC based instrumentation for eddy-current and ultrasonic inspections has made possible the availability of easy-to-interpret signal displays and powerful signal enhancement and classification algorithms. In accomplishing its objective in the development and application of signal classification tools, the investigator works closely with OEMs and airlines in the definition of problems and beta site testing of the tools. The final deliverable on this task is a user-friendly software package that can be introduced as an add-on module with existing systems with minimal hardware investment by the company.

The following applications have been the focus of this program.
1. Eddy-current inspection of turbine slots: Working closely with Honeywell Inc., in Phoenix, AZ, a tool has been developed to perform routine screening of electronic signals, namely eddy current, that reveal the position and size of flaws. C-scan images of the horizontal and vertical channel data are also provided. The ability to detect cracks in close proximity to slot edges has been demonstrated on a limited set of data provided by Honeywell. Irregular signals are flagged to allow operator intervention. Software will be transferred to Honeywell for their internal evaluation.

2. Wheel inspection: Typical wheel inspection is accomplished with an eddy-current scanning system where the wheel is rotated and the probe is held stationary or vice versa. Northwest Airlines identified the opportunity for improvements in this inspection using signal classification methods. Software which provides eddy-current C-scan images and electronic strip-charts that reveal position and size of flaws has been developed and beta site tested with NWA. An adaptive crack detection algorithm that can detect small (30 mil) cracks in the presence of noise has been demonstrated. Based on feedback from the beta site test, a mechanical marking system was developed which locates actual crack positions on the tested wheel. A nondisclosure agreement has been signed with ANDEC, a commercial vendor of wheel inspection systems, as a first step in licensing discussions. The classification software developed at ISU has been integrated with the ANDEC commercial system software and tested on a limited set of wheels with defects.

Investigator: Lalita Udpa, Iowa State University

UT for Airline Composite Inspection Requirements

Numerous composite structures, some quite aged and containing repairs and rework, are currently in service on the commercial fleet. In beta site tests of the Dripless Bubbler, which was originally designed for detecting corrosion in metallic airframe structures, the airlines applied the bubbler scanner to a number of composite and composite repairs inspection problems of their concern. The current program, designed to be responsive to the composite and honeycomb structure inspection needs of the airlines and the OEMs, is carried out in cooperation with Boeing, American Airlines, United Airlines, Northwest Airlines, AANC, and CACRC. The technique chosen for development, at the recommendation of the airlines, is the tap test–a time-honored technique for inspecting composites and metal honeycomb sandwiches. To substantially advance the technology, the project has developed an instrumented tap test that is quantitative, image-based, and capable of providing mechanical properties information of the structures. Known as the Computer Aided Tap Tester (CATT), the tapping and imaging system provides images showing the percent stiffness change due to internal substructures, repairs, flaws, and damages. In field tests conducted at airlines, military depots and OEMs, the prototype system is proven to be highly portable, easy to operate, and cost-effective. With this device, an airline inspector can make an accurate assessment of the size, shape, and severity of a flaw or damage. An OEM or maintenance and overhaul facility can use the technique to verify that the parts are fabricated or refurbished correctly. Field inspection and beta site testing approaches, as successfully implemented in previous CASR efforts, are again used to transition the new NDI tool to the airlines.

Investigators: D. Hsu, D. Barnard, and V. Dayal, Iowa State University
Industry partners: UAL, AA, NWA, Delta, Midwest Express, Boeing, EAA, Bell Helicopter, Iowa Army National Guard, Scaled Composites, NASA, and AANC

Development and Implementation of NDI Testing Techniques on Commuter Aircraft

The economics associated with the airline industry dictates the life span of fleet aircraft be extended as long as safely possible. Most major carriers have always used the latest NDI technology as a routine part of their inspection procedures to help extend the service life of their planes. In contrast, commuter aircraft are still inspected primarily through various visual methods that may be difficult to perform or which are subject to very different interpretations. In addition, these techniques provide no capability for detection of subsurface flaws or other areas that cannot be visually inspected. The project investigates inspection problems, especially new inspection requirements that are a result of damage tolerance analysis performed on aging commuter aircraft, and assesses the role conventional and advanced NDI techniques can play in solving these problems. Emphasis is placed on defining a common problem area and developing an NDI technique that is reliable, reasonably user-friendly, and falls within a price range acceptable to commuter airlines.

Specific applications were identified in cooperation with the FAA Small Transport Directorate, Fairchild, and Cessna. While development focused on the inspection system for the selected application (Fairchild SA 226 and SA 227 wing spar assembly), the end result will be a process that can be adapted for other applications as well. Inspection development has included scanning modules integrated with commercially available instrumentation. Validation activities were performed by AANC using the Fairchild Metro available at the hangar. The approach has also been demonstrated in the field, including Iron Mountain, Michigan. Formal adoption of the new inspection technique and associated procedures will come through modifications of the OEM's NDT Standard Practices Manual, SID documents, or other similar documents.

Investigators: Larry Dorrell, and Kirk Rackow, Sandia National Laboratories
Igor Komsky, Northwestern University
Industry partners: Fairchild, Cessna, and Superior Aviation

NDI Capability Characterization and Methodology Development for Aircraft Inspections

The AANC has developed a validation process for NDI equipment and procedures. The emphasis in the methodology followed by the AANC has been "blind" experimentation and a recreation of inspection conditions in order to measure reliability associated with the technique or process. However, in early stages of development NDT designers do not have complete processes defined and are often asked whether a technique or technology has basic capabilities as needed for aircraft inspection. This program developed a formal process that the AANC will follow in helping developers establish a measure of capability (as opposed to reliability) for aircraft inspection requirements.

The program steps consisted of identification and documentation of the breadth of aircraft inspections that currently use NDT. Identification of the variations of physical conditions (materials, geometries, etc.) related to those inspections was included, and the AANC has developed a four-step methodology for assessing the capability of new NDI equipment or techniques. The objective of this process is distinct from that of the reliability experiments that are conducted at the AANC and focuses on determining whether a particular system is even able to perform typical aircraft inspections. The first step in the process asks the system developer to characterize the types of inspection tasks that they believe their system is capable of performing. A series of standardized questionnaires have been developed to aid in this process. The second step is performed by the AANC in preparation for the capability assessment inspections and involves developing a test plan for the assessment. Considerations include determining which of the system designers' claims should be assessed, which test specimens should be used, the need to gather metrics other than the ability of the system to detect defects, and issues concerning how an inspector will use the signal from the system to make calls.

The test specimen selection is aided by two databases that were developed under this program; one summarizes characteristics of typical aircraft inspections and the other details the specifications of reference standards used for these inspections. With the aid of the second database, the AANC has expanded their library of test specimens used in this process. The third step in the capability assessment process has the system designers actually perform the inspections as determined in the previous step. When possible, on-aircraft inspections should also be included. The system should also be evaluated using the Human Factors Audit, which considers the usability of the system. Finally, in the fourth step, the AANC observers provide feedback to the system designers as to both the performance and usability of their system.

Investigators: Floyd Spencer and Caren Wenner, Sandia National Labs

Visual Inspection Reliability

Visual inspection is the mainstay of the nondestructive techniques used to ensure the structural integrity of aircraft, accounting for 80 to 90 percent of the inspection workload in the transport aircraft and greater than 90 percent in the commuter aircraft industry. In previous work, data has been gathered to benchmark the reliability of visual inspection and to suggest factors that may influence the reliability. Earlier efforts performed by AANC provided inspection data in a visual reliability benchmark using 12 inspectors on the Boeing 737 test bed and 11 inspectors on the Fairchild Metro II test bed. The data gathered in these efforts have shown a high inspector-to-inspector variation in inspection results. They have also shown that in a search and decision model of the inspection process, all inspectors could benefit from appropriate search interventions, whereas only a few had major failings in the decision-making (deciding that an observed anomaly was, in fact, a flaw). The work performed here planned and implemented an experiment designed specifically to address a major issue that concerns aircraft maintenance professionals – the effect of the inspection instructions on performance.

The Search Instruction Characterization Experiment was designed to address how visual inspections were impacted by the using different instructions. In the study, each inspector

inspected six areas of the aircraft over a two-day experimentation period. Six versions of the instructions for each inspection area were developed, ranging from general to a large number of directed inspections. Each inspector used all six instruction versions during the course of his inspections. The order in which tasks were completed, and the instruction version used by each inspector for each task was assigned using standard statistical methods.

Investigators: Floyd Spencer, Caren Wenner, and Mike Bode, Sandia National Laboratories
Industry partners: UAL, Continental, NWA, USAirways, Delta, BFGoodrich, and FedEx

Technology Development for Inspection of Interphase Degradation in Adhesive Bonds

Reliable techniques for inspection of adhesive joints with weak interphasial bonding (poor adhesion) constrain the use of adhesive bonding for airplane structural components. A weak adhesive joint may occur from in-service environmental degradation or from poorly controlled manufacturing processes that result in formation of "kissing bonds." There is a need for field inspection techniques that detect degraded adhesive bonds and for an inspection-based damage tolerance model for adhesively bonded structures. The principal thrust of this work is developing a field inspection apparatus for identification of environmentally degraded aircraft adhesive bonds. The inspection concept is based on the angle-beam ultrasonic method. This technique was developed in the OSU NDE laboratory over the past several years using, immersion inspection of weak adhesive bonds. The immersion technique is being successfully implemented under a Navy SBIR Phase II (Adler Consultants). The OSU team collaborates closely with Adler Consultants to develop a commercial inspection system.

Investigators: Stan Rohklin and H. Shen, Ohio State University
Industry partners: Boeing, Thiokol, United Technology, BF Goodrich, Adler Consultant, and Ohio Department of Development

Design and Quality Assurance of Premium Quality Aircraft Castings

Increased use of castings is being given consideration by both airframe and engine manufacturers. Advantages of cast structures over the conventional built-up structure are many including the following:

- Reduced part count
- Part–to–part dimensional consistency
- High structural reliability
- Improved serviceability
- Lower procurement cost and replacement cost
- Reduced system complexity with repair and maintenance safety benefits

To implement new cast components, their capability to carry design loads in the presence of damage before catastrophic failure (or prior to the next inspection interval) must be understood. An integrated approach to design that takes into consideration defect formation (type/location per casting process parameters), crack formation/growth and residual strength, and inspectability is the focus of this program.

Investigators: James Conley and Brian Moran, Northwestern University
Industry partners: Boeing, Hitchcock, Pratt & Whitney, Cercast, Howmet, and PCC Structurals

Scanning Pulsed Eddy Current for Aviation Applications

A novel pulsed eddy-current (PEC) instrument was developed at CASR. The advantages of PEC techniques include the wide bandwidth attainable, which permits, in effect, a single probe and a single measurement to provide information over a broad frequency range and, in turn, a range of depths. The information can be used to better characterize cracks and to locate them in the depth of the material. Since both low and high frequencies are present, defects can be detected at greater depths without loss of sensitivity to near-surface cracks. Prior effort led to the successful development of a prototype scanning version of the pulsed eddy-current instrument, primarily directed at quantitative measurements of corrosion loss. The first prototype system was demonstrated at several locations including AANC, Boeing-Seattle, Boeing-Long Beach, United Airlines, Air Force ALCs (Sacremento, Warner Robins, Tinker) and at the ATA NDT Forums since 1996.

Investigators: John Bowler and Marcus Johnson, Iowa State University
Industry partners: Boeing and Northwest Airlines

Development of Conformable Eddy-Current Sensors for Engine Component Inspection

This project includes the development and validation of proposed technologies for failure-critical engine parts. The goal was to develop more flexible and versatile instruments for surface inspection and to increase the state of the art for detection of manufacturing, fatigue, wear, or other surface anomalies. The patented JENTEK-developed Meandering Winding Magnetometer (MWM) eddy-current-based design and model-based data interpretation and calibration procedures were adapted to specific sensor technology or combinations of technologies for engine disk inspections. Included in the evaluation were detection of cracking in the presence of fretting, reliable detection at edges, and alpha case detection in in-service components. A specific application for the MWM array was selected and demonstrated. An upgraded version of the instrument was produced and delivered to AANC with a low–cost scanning apparatus for disk slot inspection. FAA/AANC personnel participated in a third party limited POD study to evaluate performance.

Investigators: Neil Goldfine, V. Zilberstein, A. Washabaugh, D. Schlicker, Y. Sheiretov, K. Walrath, and E. Hill, Jentek Inc.
Industry partner: FAA AANC

Critical Rotating Components – Engine Titanium Consortium

The Engine Titanium Consortium (ETC) was established in 1993 to address the inspection recommendations of the FAA Titanium Rotating Components Review Team

report (TRCRT) and had as its objective provision of reliable and cost-effective new methods and/or improvements in mature methods for detecting cracks, inclusions, and imperfections in titanium alloys used in engine applications. Building on the successful products of Phase I, the Phase II technical program began in May 1999 with three major task areas: production inspection, in-service inspection, and inspection systems capability and assessment. The following deliverables are planned for completion in the 5–year effort:

- Development of fundamental understanding of the microstructural features that impact detectability and the melt-related defects of typical nickel alloys utilized in commercial engines for use in inspectability decisions.
- Demonstration of #1FBH sensitivity inspection in nickel and titanium billet up to 10″ diameter including factory evaluation of zoned inspection for nickel billet.
- Laboratory assessment of sensitivity in titanium billet at diameters greater than 10″.
- Demonstration of #1/2FBH sensitivity inspection in titanium forgings.
- Development of best practices document for bolt hole inspection to be published as an industry standard.
- Engineering data on the effect of cleaning methods and drying methods on inspectability of FPI.
- POD estimates for ultrasonic inspection of nickel billet, titanium billet, and titanium forgings.

Investigators: Lisa Brasche and Bruce Thompson, Iowa State University
Thadd Patton and John Halase, General Electric
Andy Kinney and Waled Hasan, Honeywell
Kevin Smith and Jeff Umbach, Pratt & Whitney
Industry partners: The Engine Titanium Consortium by its design strives to bring industry together in a partnership to address inspection needs relevant to propulsion systems. In addition to the funded OEMs, GE, Honeywell, and Pratt & Whitney, others, including Rolls Royce and Snecma, have contributed to the activities of ETC. Close partnerships have existed with the major U.S. aircarriers through participation at the ATA NDT Forum, SAE Committee K, and individual contacts. Communication also continues with the billet and forging suppliers.

A Inspection for Critical Rotating Components – Laser Based Ultrasonic Inspection for Disks

Conventional ultrasonic flaw detection methodologies require the generation of an ultrasonic wave packet that travels through a structure, and the subsequent detection of reflections of this wave packet from any existing flaws within the structure. Laser-based ultrasonics has thus far followed the same methodology except that the generation and detection of the ultrasonic wave packets were done using lasers. The limitations on the size of flaws that can be detected using this approach are set by the ultrasonic reflectivity of the flaws for the particular wavelength of the probe signals. Due to the small reflectivity of very small flaws, the reflected wave packets are often too weak to be detected with existing laser detectors.

In this project we are developing an alternate approach for ultrasonic detection of surface-breaking small cracks using laser-based techniques. In this approach, the

ultrasound generation source, which is a point- or line-focused high-power laser beam, is swept across the test specimen surface and passed over any existing surface-breaking flaw. The generated surface ultrasonic wave packet is detected at a fixed location on the test specimen. It is found that the amplitude of the measured ultrasonic signal has a specific variation when the laser source approaches and passes over the defect. Proof of concept experiments have been carried out for flat specimens with EDM notches of various sizes and on an actual engine disk, all of which were provided by Honeywell (AlliedSignal Engines).

Investigators: Sridhar Krishnaswamy, Northwestern University
Industry partner: Honeywell

Infrared Detection of Ultrasonically Excited Cracks

Thermal wave imaging research has been a key element of the FAA's aviation safety program since the early 1990s. Through development and technology transfer studies in cooperation with AANC, the technology was recently approved as an acceptable in-service inspection procedure by Boeing. Prior work focussed primarily on the detection of disbonds and corrosion damage in metallic structures and impact damage in composites. Crack detection received little attention. Recently, through communication with a scientist at the University of Stuttgart, WSU staff began studies of acoustically assisted thermal wave imaging. The essence of this technique is to cause the crack to light up, using an applied ultrasonic field. In a simple picture, one can imagine that the two sides of the crack are rubbed and banged together by the ultrasonic waves, and the crack gets hot. It is the ultrasonic field, rather than a flash lamp, that is providing the heat source for the IR camera. Since the unbroken skin of the plane is only minimally heated by the ultrasonic waves, the resulting images of cracks are seen as bright features against a dark background field, thus providing the potential for detecting extremely small cracks with very high sensitivity. A patent has been filed by WSU based on prior work.

Investigators: Bob Thomas, L.D. Favro, and X. Han – Wayne State University

NDI Guidance Material for FAA Aircraft Certification Engineers

The Federal Aviation Administration has unique responsibilities for the certification of new designs and assurance of the safe continued operation of commercial aircraft. A work force with broad knowledge of the design, manufacture, operation and maintenance of the aircraft, propulsion systems, and auxiliary systems is required. Nondestructive evaluation (NDE) is a key technology element that supports the overall lifecycle needs of aviation. NDE uses noninvasive sensing technologies to determine the integrity, or fitness for service, of an engineered system for its intended purpose. Typical technologies in use by the aviation industry include visual, penetrant, magnetic particle, eddy current, ultrasonic, and radiographic inspection. FAA certification engineers are required to assess the appropriate use and frequency of inspection methods for the continued airworthiness of the commercial fleet, including large transports, small transports, and rotorcraft. Guidance materials that provide background information on relevant technologies, including expected performance metrics, and relationship to life

management practices is needed. The purpose of this program was to work with the FAA's Chief Scientist and Technical Advisor for NDE and FAA certification engineers to define instructional needs and develop representative materials for used for assessing NDE applications. Both written (hardbound) and electronic media will be considered for delivery of the materials.

Investigators: Lisa Brasche and David Eisenmann in response to requests from members of the Aircraft NDI Technical Community Research Group (TCRG).

Enhanced Flaw Detection Using Hall Probes for Aircraft Inspection

The key objective of this project was to develop a new probe technology with enhanced flaw detection capability, using multi-sensor field measurements to accelerate inspections. The work was motivated by a need to improve flaw detection and the need to reduce inspection time in a cost-effective way. The objectives will be accomplished through the development of novel eddy-current probes based on a new generation of high-sensitivity, semiconductor magnetic field sensors. The sensors will be custom made at the Microelectronics Research Center (MRC) at Iowa State University (ISU) and integrated into probes designed and constructed at the Center for Nondestructive Evaluation (CNDE). The combination of thin layer techniques and novel semiconductor materials has been shown to produce devices with high carrier mobility, at least an order of magnitude greater than that for silicon. The implication of this finding is that Hall sensors can be produced with a much higher sensitivity than those generally available from component manufacturers. Material and structural studies will be carried out to find the optimum sensors. These will then be used to fabricate probes for nondestructive evaluation. The sensors will be configured in four different ways:

- Single pick-up with an excitation coil
- Linear array for rapid area inspection
- Circular planar array for the inspection of small fatigue cracks under installed fasteners
- Circular cylindrical array for the inspection of bore holes, holes with an installed bushing, or fastener holes with the fastener removed

Investigators: John Bowler, Marcus Johnson, Garry Tuttle, Iowa State University

NDE Technology Assessment and Infrastructure Support
Program initiation date: Awarded as IA044, September 17, 2001

This task provides technical support to the FAA-CASR, ETC, and AANC programs. The participants of this project are available to work with the staff of each of these programs, the FAA, and industry in support of short-term projects and the development of test samples. Short-term projects and specimen needs are brought to the attention of the CASR staff through interactions with the FAA directorates, William J. Hughes Technical Center staff, FAA Chief Scientist and Technical Advisor for NDE, and industry contacts. This task will also serve to produce an improved understanding and documentation of the science and techniques involved with various NDE technologies, including the FAA's participation in the Center for NDE's Industry/University Cooperative Research

Program. This program brings together over 20 industry sponsors to collectively direct and fund basic research that has common value to the sponsors. Participation provides the FAA with the earliest possible exposure to advanced research results and interaction with NDE leaders from the aviation industry. Literature reviews and summary reports of published data will also be prepared to provide an understanding of previous research results, with focus on aviation-related data. This information is very useful when trying to understand current industry practices and when developing collaborative research efforts. Having a firm understanding of the procedures and results of previous work is particularly important in collaborative efforts involving industry. Industry participants often have a different perception of the previous research results and current needs. The summary reports help to bring everyone to a common level of understanding. Prior efforts, selected from input provided by the FAA NDE-NRS, AVR personnel, and industry partners from the ATA NDT Working Group, have been well received and broadly used. Additional studies of this type are planned with the topics to be defined in cooperation with the TCRG and industry partners.

Investigators: Brian Larson and Rick Lopez, Iowa State University

Data Analysis Tools for Aircraft Inspections
Program initiation date: Awarded as IA045, September 17, 2001

Nondestructive inspection plays a critical role in the overall safety of the aircarrier fleet, with eddy-current inspection being the most readily used method after visual inspection. Eddy-current methods have the advantage of being sensitive to near-surface cracks, including multiple layers and other material property changes that affect conductivity. However, the method is also sensitive to geometrical changes in the component such as edges. The need for accurate signal interpretation which can distinguish nominal geometry or material changes from flaw signals is critical in making the right decisions during nondestructive inspection of aircraft components. The advent of PC-based instrumentation for ultrasonic and eddy-current inspections have made possible the availability of easy-to-use signal processing software that can help in the operator's analysis of the measured signals. This project is related to development of a PC-based signal processing toolbox that addresses the needs of the aviation industry.

Several applications have been identified in cooperation with the OEMs which could benefit from the application of automatic data analysis (ADA) systems. Controlled data taken with wide-area, eddy-current probes is seeing more use in the industry. Wide-area probe technology offers time savings as a wider area is inspected in a single pass. However, additional understanding of the sensitivity of this new technology and the implications for signal analysis is needed. One such application is the dovetail slot inspection used in some engine disks. The major issue in this inspection is proximity of defects to edge, whereby the overwhelming contribution of the edge signal distorts the flaw signal. Similar problems arise in other inspections such as eddy-current rotating probe inspection of rivet holes, sliding probe inspection signals, and ultrasonic data. A general-purpose signal processing toolbox that addresses the various needs of different inspection problems can be of significant value to the operator.

Investigator: Lalita Udpa, Michigan State University

Industry Support: NWA, Delta, and Honeywell

Detection of Disbonds and Assessment of Structural Integrity of Composite Repairs for Aircraft Components

Disbonding is the primary defect in composite repair of aircraft components. It maybe caused by poor surface preparation, thermal mismatch, or moisture and other chemical contamination, etc. These defects can occur during the repair or after prolonged exposure. In addition, aging can cause peel-out of composite layers due to asymmetric load path. Therefore, the quality assurance of repairs made on composite components and the predictability of the remaining service life of the repaired parts is essential to their continued airworthiness. Proposed is a joint effort performed by North Carolina A&T State University's Center for Composite Materials Research (CCMR) and Iowa State University's Center for Aviation Systems Reliability (CASR). This effort combines the excellence of the two centers to solve a multidisciplinary problem of composite repair. Completion of this research will yield assessment tools for detecting disbond in composite repairs and its effect on the strength and life of aircraft components. The specific tasks are to:

- Identify types and procedures of composite repairs.
- Perform composite repair with and without disbonds on composite material parts. The repairs are to be performed according to aircraft manufacturers (such as Boeing) specifications, guidelines, and/or standards.
- Perform nondestructive testing of the repaired parts at CASR (Iowa State University) by using C-SCAN and Computer Aided Tap Test (CATT) systems.
- Perform destructive measurement of damage in repaired parts to map the damage size, mechanical properties, fatigue life, and residual strength.
- Correlate the measured damage to the NDT measurements and assess the detectability of NDT techniques.
- Develop finite element models and perform stress analysis along with fracture mechanics analysis to assess the severity of the disbond. Correlate the severity of project management.

Investigators: Sameer A. Hamoush, Derome Dunn, Kunigal Shivakumar, and Mathew Sharpe, North Carolina A&T University

Development of Nondestructive Inspection Methods for Repairs of Composite Aircraft Structures

The use of composites on aircraft is steadily increasing and has begun to enter applications that include primary load-bearing structure categories. The capability to repair composite components is a key technology for continued airworthiness; it follows that the integrity and quality of repairs must be assured. However, the nondestructive evaluation of repairs on composite structures is a challenging task because a repaired region is considerably more complex than the original structure. NDI techniques and instruments for composite repairs are very much lacking, especially for field repairs performed without the benefits of an autoclave.

In field tests and beta site tests for the CATT system, the various airlines have consistently identified the inspection and evaluation of repairs on composite structures as a key technical issue that requires research and development support. With the increasing use of composites on control surfaces and, more recently, on primary load-bearing structures of the aircraft, the quality assurance of repairs made on such components is essential to their continued airworthiness. Unfortunately, NDI techniques for composite repairs are very much lacking. Field practice still relies largely on hearing-based manual tap tests. We therefore propose an R&D effort to develop NDI techniques for mapping out the morphology and mechanical condition of a repair, to establish a correlation between imaged features and the actual internal state of the repair, and thereby help to establish the accept/reject criteria for repaired components. The main emphasis will be to adopt the CATT system for quantitative NDE of composite repairs. A significant side benefit of developing the CATT system for inspecting composite repairs is that it would lead to a low-cost NDI scanner as a result. However, due to the complexity of a repaired zone and the variety of possible flaws it may contain, a number of methods, including resonance and mechanical impedance techniques, will be employed and compared. In addition to the conventional methods, this task will also explore and develop air-coupled ultrasound for the inspection of composites and their repairs. With air-coupled transducers, both through transmission scans and one-sided generation of Lamb waves will be applied to a variety of composite structures and repairs thereon.

Investigators: David K. Hsu (PI), Daniel J. Barnard, John J. Peters, and Vinay Dayal, Iowa State University.
Industry Support: Jeff Kollgaard, Boeing, Jerry Doetkott, Northwest Airlines, Jack Conrad, American Airlines, Dennis Roach. AANC, Tom Dreher, et al., CACRC , and Gary Penney, British RAF.

Nondestructive Evaluation of Premium Aerospace Castings

The complexity of casting designs is becoming greater as casting houses develop better methods for determining the quality of a casting and therefore become more confident in their performance. The significant improvement in casting quality, especially with the tighter control in the material properties, has triggered a considerable interest in castings as a means to replace built-up structure in airframes. Boeing and Airbus are using castings for more components, in the case of Airbus; a passenger door is now being made from a monolithic casting. The inspection issues with these new components are critical as the applications for these cast parts becomes more wide spread. It necessarily also increases the FAA's attention to these new applications and their implementation in a safe manner. The complexity of an access door requires a considerable number of views (x-ray inspections) to ensure adequate coverage. This issue of coverage needs to be considered and optimized. Additional issues that impact the use of cast parts is the advent of digital imaging systems. The digital data allows the opportunity of improved detection over human only review of data. The improvements introduced by matched filters and hypothesis testing noise reduction coupled with the automation of the inspection that digital data allows represent significant improvements in the reliability of the inspection. Due to the quantitative nature of the data, effects such as scattering,

undercut, and detector effects introduce distortions in the image that need to be understood for quantitative sizing to be done. The basic drive in this project is to develop the quantitative understanding of the subtler image effects, develop improved image processing tools and apply this knowledge to optimized inspection coverage of complex aerospace castings. While useful to industry in implementation of new designs, the results will also assist the FAA in certification decisions regarding new inspection methods to support these changes in design philosophy.

Investigators: J. Gray (PI), F. Inanc, T. Jensen, and J. Xu, Iowa State University.
Industry Support: Boeing, Howmet, Northrop Grumman, and Hitchcock.

Multi-Element Adjustable Transducer Arrays For Applications With Portable Ultrasonic Flaw Detectors

A team of university and industry researchers will develop a set of multielement adjustable ultrasonic transducer arrays to use in a variety of ultrasonic inspection procedures and the transfer this technology to the aircraft industry. The arrays will be integrated with the commercially available portable ultrasonic units. The arrays will be used to detect and characterize fatigue cracks and corrosion, as well as to monitor the sealant quality in the multilayered airplane structures, from the airplane skin without disassembly. Consideration will be given to combine multiple measurements into a single information set from multiple-zone, multiple-depth inspections of aircraft structures.

Investigators: Igor Komsky, Northwestern University
Industry Support: Boeing-Long Beach, Boeing-Seattle, Northwest Airlines, Cessna, AANC, Panametrics, Krautkramer-Branson, Sigma, and Technisonic

Magnetic Particle Inspection Improvements for Aerospace Applications

The magnetic particle inspection technique has been used for many years in aviation applications, but unfortunately very few aids exist that assist in proper test setup. There are many rule-of-thumb equations available to calculate current settings for a given sample geometry, but very often this results in gross over-magnetization and reduced sensitivity. Further, magnetic particle test specifications prescribe current values that are affected by the control waveforms used for regulating the current intensity. This introduces harmonics in the waveforms that makes it difficult to establish a relationship between peak and rms values of a current waveform, which is important in the practical use of MPI. Each of the waveforms has its own characteristics and interactions between leakage fields at discontinuities and the particles can vary significantly. It is, therefore, possible to miss the detection of defects by choosing inappropriate current waveforms. In recent Air Transport Association NDT Forums (1999 and 2000), the airlines have identified the need for additional research to support fundamental understanding of the MPI technique and the factors which affect sensitivity. Of particular concern is the direction “complete 100% magnetic particle inspection” which is commonly found in OEM procedures. The ability to assure that a particular technique is adequate is now questionable. This program is aimed at developing an easy to use simulation program that will address the issues defined by airline and OEM users. The tool will assist by

reducing test setup time and by identifying sample regions that may have reduced magnetic flux density. This will prove quite useful to industry in assessing the effectiveness of a given technique. The simulation program will provide accurate estimations of magnetic field intensity both inside and outside of the sample, and will take into account power supply variability, which will reduce overall procedure development time and allow determination of part geometry effects. A complimentary effort is underway to generate a literature survey of the factors that affect the sensitivity of magnetic particle inspection. The survey, which covers public domain data from 1970 to 1999, will be used to assess relevant factors for inclusion in the simulation tool.

Investigators: Lisa Brasche, David Jiles, Mike Garton, Iowa State University
Industry Support: United Airlines, Pratt & Whitney, and Boeing

MOI Sensor Improvements

Along with the increase in air travel throughout the world, is the growing population of aging aircraft. Accordingly, inspection requirements to ensure continued aircraft airworthiness has created a need for cost-effective NDI techniques that are accurate, reliable, and easy to use. Magneto-optic imaging (MOI) is such a technique, which has gained wide acceptance, including use by Boeing and Airbus, for detection of both surface and subsurface defects in commercial aircraft. This research program strives to improve the MOI for the detection of smaller defects such as corrosion and fatigue cracks in multilayer aircraft structures as requirements become more stringent for the detection of such defects in the aging fleet. Specifically, the proposed improvement will be to the magneto-optic sensor used in the MOI device. In the past, feasibility was demonstrated by using practical (extrinsic) fabrication methods (e.g., cobalt button deposition) to improve the high-temperature, image-forming characteristics of garnet films, which are the basis of magneto-optic sensors. This improvement has now been fully integrated into current commercial MOI products. However, there is a significant opportunity and need for practical (intrinsic) methods of increasing *sensitivity* and improving *temperature stability* of magneto-optic garnet films. Accordingly, the intrinsic properties of magneto-optic sensors (i.e., so-called "out-of-plane" magneto-optic sensors) will be improved by exploring different chemical compositions than the currently available out-of-plane sensors and varying methods of film growth and/or annealing histories. It has also been determined that sensors of a type not previously considered for magneto-optic imaging in the MOI (i.e., so-called "in-plane" magneto-optic sensors) could lead to major advances in magneto-optic imaging technology. Accordingly, the properties of this type of sensor will be explored. Electromagnetic (finite element) calculations, designed to guide the sensor development and improvement process, will also be carried out. A team composed of PRI Research & Development Corp (PRI), the developers and manufacturers of the MOI, ISU, OSU, and Northrop-Grumman Synoptics (Synoptics) will perform the proposed 2-year effort.

Investigators: Bill Shih and Jerry Fitzpatrick, PRI
Lalita Upda, MSU.
Industry Support: PRI Research and Development Corporation (PRI), Northrop-Grumman Synoptics, Michigan State University, and Ohio State University.

Engineering Assessment of Fluorescent Penetrant Inspection

Fluorescent penetrant inspection (FPI) is a widely used inspection technique for surface crack detection in both aircraft and engine components being used for both production qualification and in-service assessment. In a recent survey of airworthiness directives from 1995– 999, FPI was the third most frequent inspection called out behind visual and eddy-current inspection methods. Although patented in 1941, significant changes have occurred in the chemicals/chemistry associated with the process, in many cases as a result of environmental considerations. The program will determine the most relevant factors for which existing data is insufficient, assess the parameter ranges that provide acceptable performance for typical aircraft and engine components, and document the results of these studies. Program plans and results will be coordinated with industry partners to ensure they are applicable to aerospace practices and relevant specification modifications will be supported through participation in standards committees such as SAE Committee K. In addition to engineering studies, other needs identified through industry input will also be addressed. These include self–assessment tools that can be used by the airlines and OEMs to determine effectivity of internal processes and documentation of results which can be used by the industry in effectively instructing personnel in proper processing. Workshops will be used to keep the FAA and industry partners fully informed of progress and results.

Investigators: Lisa Brasche, Rick Lopez, Dave Eisenmann, Brian Larson, and Bill Meeker, ISU
Industry Support: Clint Surber and Steve Younker, Boeing – Seattle
Dennis Smith and Dwight Wilson, Boeing – Long Beach
Lee Clements, Delta Airlines
Tom Dreher, United Airlines
Kevin Smith, John Lively, and Anne D'Orvilliers, Pratt & Whitney
Bill Griffiths, Keith Griffiths, and Pramod Khanderwal, Rolls Royce
Sam Robinson, Sherwin
Ward Rummel, D&W Enterprises

Publications

Augustinus, J., Lacy, T.E., and Tomblin, J.S., "Modeling Impact Damage in Sandwich Composites," *Symposium on Design and Manufacturing of Composites International Mechanical Engineering Congress and Exhibition, Orlando*, Florida, November 5-10, 2000.

Chaparro, A. Groff, L., Chaparro, B.S. and Scarlett, D. (in press) "Human Factors Survey of Aviation Technical Manuals Phase II Report: User Evaluation of Manual Quality," 16th Symposium on Human Factors in Aviation Maintenance, San Francisco, California.

Chaparro, A. and Groff, L., (2001), "Human Factors Survey of Aviation Technical Manuals Phase 1 Report: Manual Development Procedures," Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.

Chaparro, A., Groff, L., Chaparro, B.S., and Scarlett, D., (2001), "Human Factors Survey of Aviation Technical Manuals Phase 2 Report: User Evaluation of Maintenance Documents," Washington, DC, Federal Aviation Administration, Office of Aviation Medicine.

Ghosh, S., "Modeling of Ti-6242 alloys for Creep and Deformation," FAA annual Technical Review, August 2000.

Ghosh, S., "Modeling of Ti-6242 alloys for Creep and Deformation," FAA annual Technical Review, August 2001.

Han, N.L., Suh, S.S., Hahn, H.T., Yang, J.-M., Shyprykevich, P., and Lee, S.M., "Manufacturing of Stitched Composite Panels," Proceedings American Society for Composites, *14th Technical Conference*, 2000, pp. 889-895.

Hasjia, V., Joseph, D. Ghosh, S., and Mills, M.J., "A Finite Element model for Deformation and Creep Modeling in Ti-alloys," to be submitted.

Huang, H., Yang, C., Tomblin, J.S., and Harter, P., "Stress and Failure Analyses of Adhesive-Bonded Composite Joints Using ASTM D 3165 Specimens," *ASTM Journal of Composite Technology and Research*, JCTRER, Vol. 24, No.2, April 2002.

Hwang, Y. and Lacy, T.E., "Numerical Modeling of Impact Damaged Sandwich Composites Subjected to Compression After Impact Loading," *14th U.S. National Congress of Theoretical and Applied Mechanics*, Blacksburg, Virginia, June 23-28, 2002. Paper to be considered for publication in *Composite Structures*.

Joseph, D.S. and Ghosh, S., A, "Voronoi Cell Finite element model for polycrystalline materials."

Kim, H., "The Buckling Stability of Disbonds in Composite Adhesive Lap Joints," *Proceedings of the 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials (SDM) Conference*, April 22-25, 2002, Denver, CO.

Kim, H. and Kedward, K.T., "The Design of In-Plane Shear and Tension Loaded Bonded Composite Lap Joints," *ASTM Journal of Composite Technology*, April 2002.

Kim, H. and Kedward, K.T., "Stress Analysis of Adhesive Bonded Joints Under In-Plane Shear Loading," *Journal of Adhesion*, Vol. 76, No. 1, 2001, pp. 1-36.

Kim, H. and Kedward, K.T., "Stress Analysis of Adhesively-Bonded Composite Joints Having Varying Bondline Thickness," *16th Annual ASC Technical Conference on Composite Materials*, September 9-12, 2001, Blacksburg, VA.

Lacy, T.E., Samarah, I.K. and Tomblin, J.S., "Damage Resistance Characterization of Sandwich Composites Using Response Surfaces," *SAE General Aviation Technology Conference and Exhibition*, Wichita, Kansas, April 16-18, 2002.

Lacy, T.E., Samarah, I.K., and Tomblin, J.S., 2002, "Damage Tolerance Characterization of Sandwich Composites Using Response Surfaces," Proceedings, *American Society for Composites 17th Annual Technical Conference*, Purdue University, West Lafayette, Indiana, October 21-23, 2002.

Lacy, T.E., Samarah, I.K., and Tomblin, J.S., 2002, "Damage Resistance Characterization of Sandwich Composites Using Response Surfaces," SAE Paper 2002-01-1538, Proceedings, *Society of Automotive Engineers General Aviation Technology Conference & Exhibition*, Wichita, Kansas, April 16-18, 2002. Paper to be considered for publication in the *SAE Transactions*.

Lapointe, J., Leonelli, F., Chaparro, A., & Groff, L. (2000). "Assessment of Aviation Maintenance Technical Manuals," *AIAA 2000*, Pisa, Italy.

MacDonald, C. D. and Vizzini, A. J. "Response of Indented Sandwich Panels," *Journal of Thermoplastic Composite Materials*, Vol. 15, No. 1, January 2002, pp. 33-42.

MacDonald, C. D. and Vizzini, A. J., "Response of Indented Sandwich Panels," Proceedings, *American Society for Composites Fifteenth Technical Conference on Composite Materials*, College Station, TX, September 2000, pp. 275-281.

Moody, R. C., Harris, J. S., and Vizzini, A. J., "Scaling and Curvature Effects on the Damage Tolerance of Impacted Composite Sandwich Panels," *Journal of Sandwich Structures and Materials*.

Moody, R. C. and Vizzini, A. J., "Incorporation of a Compliance Change Due to Impact in the Prediction of Damge Growth in Sandwich Panels," Proceedings, *13th International Conference on Composite Materials*, Beijing, China, June 2001.

Raju, K.S., Tomblin, J.S., Lacy, T.E, and Smith, B.L., "The Residual Strength of Composite Sandwich Panels with Various Levels of Low Energy Impact Damage," *SAE Aerospace World Aviation Congress and Exposition*, Structures Session on Durability and Damage Tolerance of Composites, San Francisco, California, October 1999.

Raju, K. S., and Tomblin, J. S., "Damage Characteristics in Sandwich Panels Subjected to Static Indentation using Spherical Indentors", *42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, 16-19 April 2001, Seattle, WA.

Raju, K.S., and Tomblin, J.S., "Compressive Behavior of Impact Damaged Thin Skinned Honeycomb Core Sandwich Panels", *43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, 22-25 April 2002, Denver, CO.

Samarah, S., Lacy, T.E., and Tomblin, J.S., "Damage Tolerance and Residual Strength Characterization of Impact Damaged Composite Sandwich Structures Using Design of Experiments," *SAE Aerospace World Aviation Congress and Exposition*, Structures Session on Durability and Damage Tolerance of Composites, San Francisco, California, October 1999.

Seneviratne, W.P. and Tomblin, J.S., "Adaption of the Iosipescu In-Plane Shear Test Method for High Strength Composite Specimens," *Journal of Composites Technology and Research*, JCTRER, Vol. 23, No. 4, October 2001, pp. 259-266.

Shyprykevich, P., Tomblin, J.S., and Vangel, M.G., "The Development and Use of a Common Database for Composite Materials," *Symposium on Composite Materials Testng, Design and Acceptance Criteria*, American Society for Testing and Materials, Phoenix, AZ, March 26-27, 2001.

Sinha, V., "The Evaluation of Cold Dwell Fatigue", presented at GE Aircraft Engines, Cincinnati, OH, November 15, 2001.

Sinha, V., Blank, J., Mills, M.J., Schwarz, R.B., and Williams, J.C. "Effects of Microstructure and Micro-texture on Dwell-Fatigue Susceptibility of a near-a Titanium Alloy", David L. Davidson Symposium on Fatigue: Material Design for Fatigue Performance, TMS Annual Meeting, Seattle, WA, February 17-21, 2002.

Smith, B.L., Liew, H.K.J., Guarddon, J.C., Tomblin, J.S. and Haque, A.K.M., "Damage Tolerance of Honeycomb Sandwich Composite Panels," *SAE General Aviation Technology Conference and Exhibition*, Wichita, KS, April 16-18, 2002.

Suh, S.S., Hahn, H.T., Han, N.L., Yang, J.-M., Shyprykevich, P., and Lee, S.M., "Damage Tolerance of Stitched Panel With Stiffeners," Proceedings, American Society for Composites, *14th Technical Conference*, 2000, pp. 881-888.

Suh, S. S., Han, N. L., Yang J.-M., and Hahn, H. T., "Effect of Stitching on Compression Behavior of Stiffened Composite," ASME IMECE 2001.

Suh, S.S., Park, J.H., and Hahn, H.T., "Stitching Effect on Textile Composites," Proceedings, *2nd Asian-Austrasian Conference on Composite Materials*, 2000, pp. 1199-1204.

Tomblin, J., Harter, P., Yang, C., and Seneviratne, W., "Characterization of Thick-Bondline Adhesive Joints," *American Society for Composites 15th Annual Technical Conference*, College Station, TX, September 9-13, 2000.

Tomblin, J.S., Harter, P., Seneviratne, W. and Yang, C., "Characterization of Thick-Bondline Adhesive Joints," *ASTM Journal of Composite Technology and Research*, JCTRER, Vol. 24, No.2, April 2002.

Turner, K. M., and Vizzini, A. J., "Response of Impacted Sandwich Panels with Integral Stiffeners," *Journal of Sandwich Structures and Materials*.

Turner, K. M. and Vizzini, A. J., "Response of Impacted Sandwich Panels with Integral Stiffeners," Proceedings, *AIAA/ASME/ASCE/AHS/ASC 42nd Structures, Structural Dynamics and Materials Conference*, Seattle, WA, April 2001, CD-ROM.

Williams, J.C., "The Evaluation of Cold Dwell Fatigue," FAA-ANE, Boston.

Williams, J.C. "The Evaluation of Cold Dwell Fatigue," FAA-TOGAA, Phoenix, AZ, February 20, 2002.

Xie, Z.-H. and Vizzini, A. J., "The Presence of a Delamination in Damage Growth of an Impacted Sandwich Panel," Proceedings, *American Society for Composites Sixteenth Technical Conference on Composite Materials*, Blacksburg, VA, September 2001.

Yang, C., Guan, Z., Tomblin, J.S., and Sun, W., "Failure Analyses of Adhesive-Bonded Single-Lap Joints Using ASTM D 5656 and ASTM D 3165 Specimens," *ASME Journal of Engineering Materials and Technology,* December 2001.

Yang, C., Guan, Z., Tomblin, J.S., and Sun, W., "Failure Analyses of Adhesive-Bonded Single-Lap Joints using ASTM D 5656 and ASTM D 3165 Specimens," *ASME Energy Sources Technology Conference & Exhibition*, Houston, Texas, February 4-6, 2002

Yang, C., Huang, H., Tomblin, J.S., and Oplinger, D., "Evaluation and Adjustments for ASTM D 5656 Standard Test Method for Thick-Adherend Metal Lap-Shear Joints for Determination of the Stress-Strain Behavior of Adhesives in Shear by Tension Loading," *Journal of Testing and Evaluation*, JTEVA, Vol. 29, No.1, January 2001, pp. 36-43.

"Safety Benefits and Certification Assessment of Nonlinear Adaptive Flight Control," Rolf Rysdyk, Interim Project Report, FAA Tech Center.

Albanese, R., Rubinacci, G., Tamburrino, A., Ventre, A., Villone, F., Xuan, L., Shanker, B., and Udpa, L., "A Comparative Study of Finite Element Models for Magneto-Optic Imaging Applications", ENDE 2001, University of Cassino, Italy, June 2001.

Ahmed, S., Roberts, R., and Margetan, F.J., "Ultrasonic Beam Fluctuation and Flaw Signal Variance in Inhomogeneous Media," *Rev. of Prog. in QNDE, Vol.19A*, D.O. Thompson and D.E. Chimenti, eds., AIP, Melville NY, 2000, pp. 985-991.

Barnard, Daniel J., Peters, John J., and Hsu, David K., "Development of a Magnetic Cam for the Computer Aided Tap Test System," Review of Progress in Quantitative NDE, Vol. 20, AIP, 2001.

Bai, Tao, "Impedance spectroscopy to Investigate Aircraft Wire Insulation Aging", *AACE 3rd Annual Symposium*, Student Presentation.

Bashyam, M, and Suh,U., "Multimodality 3D Visualization of Hard Alpha in Titanium Billets Utilizing CT X-Ray and Ultrasonic Imaging," QNDE, 1998.

Connor, Z., Fine, M., and Moran, B., "A Study of Fatigue Crack Generation and Growth in Riveted Alclad 2024T3 Specimens" in Proceedings, *FAA-NASA Symposium on the Continued Airworthiness of Aircraft Structures*, DOT/FAA/AR-97/2, II, 1997.

Connor, Z. M., Fine, M. E., Achenbach, J. D., and Seniw, M. E., "Using Scanning Acoustic Microscopy to Study Subsurface Defects and Crack Propagation in Materials," *The Minerals, Metals & Materials Society*, 1998.

Connor, Z. M., Fine, M. E., and Achenbach, J. D., "Quantitative Investigation of Surface and Subsurface Cracks Near Rivets in Riveted Joints Using Acoustic, Electron and Optical Microscopy," *The Second Joint NASA/FAA/DoD Conference on Aging Aircraft*, 1998.

Connor, Z. M., Fine, M. E., and Achenbach, J. D., "Acoustic, Electron and Optical Microscopy Visualization of Surface and Sub-Surface Cracks," Review of Progress in NDE, 1997.

Connor, Z. M., Li, W., Fine, M. E., and Achenbach, J. D., "Fatigue Crack Initiation and Growth in Riveted Specimens: An Optical and Acoustic Microscopic Study," *Int. J. Fatigue*, Vol. 19, Sup. No. 1, pp. S331-S338, 1997.

Chao, C., Udpa, L., Fitzpatrick, G., Thome, D., and Shih, W., "Finite-Element Predications of MOI Performance for Application to Ageing Aircraft Inspection," *ISSS-SPIE Smart Materials, Structures and Systems*, Bangalore, India, July 1-10, 1999, pp. 515-522.

Chao, C., Xuan, L., Udpa, L., Fitzpatrick, G., Thome, D., and Shih, W., "Parametric Studies of Magneto Optic Imaging Using Finite-Element Models, *Review of Progress in Quantitative Nondestructive Evaluation*, D. O. Thompson and D. E. Chimenti, eds., Vol. 19, Plenum Press, NY, pp. 1947-1954, 2000.

Chen, Drury, Wenner and Spencer, "Designing for NDI System Usability," AANC Report, 1999.

Chiou, C.P., Yalda, I., Margetan, F.J., and Thompson, R.B., "The Use of Ultrasonic Flaw and Noise Models in Designing Titanium Test Blocks", *Review of Progress in QNDE, 17B*.

Crouse, B., Gray, J., Larson, B., "Technology Transfer Using XRSIM as a Training Tool", *Review of Progress in Quantitative NDE*, vol.17,p 2085, D. Thompson and D. Chimenti, eds., Plenum Press, 1998.

Dayal, V, Choudhary, T.A., Hsu, D.K., Peters, J.J. and Barnard, D.J., "Finite Element Modeling and Imaging by Instrumented Tap Testing", Winter Annual Meeting of the ASME, November 14-19, 1999, Nashville, TN.

Eua-anant, N., Cai, X., Udpa, L., Chao, J., and Elshafiey, I., "Crack Detection in Eddy Current Images of Jet Engine Disks," *Review of Progress in Quantitative Nondestructive Evaluation*, D. O. Thompson and D. E. Chimenti, Eds., Vol. 19, Plenum Press, NY, pp. 773-780, 2000.

Eua-anant, N., Elshafiey, I., and Udpa, L., "A Novel Image Processing Algorithm for Enhancing the Probability of Detection of Flaws in X-ray Images," *Review of Progress in Quantitative Nondestructive Evaluation*, Vol. 15, D. O. Thompson and D. E. Chimenti, eds., Plenum Press, New York 1996, pp. 903-910

Eua-anant, N., Udpa, L., and Chao, J., "Morphological Processing for Crack Detection in Eddy Current Images of Jet Engine Disks," *Review of Progress in Quantitative Nondestructive Evaluation*, Vol. 18, D. O. Thompson and D. E. Chimenti, eds., Plenum Press, NY, 1999, pp. 751-758.

Fine, M. E., Connor, Z. M., and Achenbach, J. D., "Early Stages of Fatigue Damage in Riveted Alclad 2024-T3 Aluminum Alloy Lap Joint Specimens," Nondestructive Evaluation and Materials Properites IV, P. K. Liaw, R. J. Arsenault, R. E. Green, Jr., K. L. Murty and R. B. Thompson, eds., *The Minerals, Metals & Materials Society*, 1999.

Favro, Lawrence D., Han, Xiaoyan, and Thomas, Robert L., "Thermal Wave Imaging of Defects in Fiber-Reinforced Composites," Proceedings, *SPIE Conf. on Non-Destructive Evaluation of Aging Aircraft, Airports, and Aerospace Hardware II*, 31 March to 2 April 1998, San Antonio, Texas, SPIE Vol. 3397, pp. 129-134 (1998).

Favro, L.D., Thomas, R.L., and Han, X., "State-of-the-Art of Thermal Wave Imaging for NDE of Aging Aircraft," *SPIE Conference 3586, Nondestructive Evaluation Techniques for Aging Infrastructure & Manufacturing,* Newport Beach, CA, 3-5 March, 1999, pp. 94-97.

Favro, L. D., Han, Xiaoyan, and Thomas, R. L., "Quantitative Thermal-Wave Measurement of Defects in Composite Aircraft Structures," Proceedings *44th International SAMPE Symposium and Exhibition*, Long Beach, CA, May 23-27, 1999.

Fulwood, Hr. H. L., and Moore, D. G., "FAA Fluorescent Penetrant Laboratory Inspections," Third Annual Symposium, Summer Technical Student Internship Program, Albuquerque, New Mexico, August 4, 1998.

Favro, L.D., Thomas, R.L., Han, Xiaoyan, Ouyang, Zhong, Newaz, Golam, and Gentile,

Dominico, "Sonic Infrared Imaging of Fatigue Cracks, *The International Journal of Fatigue*, 23, pp. 471-476, 2001.

Favro, L.D., Han, Xiaoyan, Li, Li, Ouyang, Zhong, Sun, Gang, Richards, Austin, and Thomas, R.L., "Thermosonic Imaging for NDE," *Review of Progress in Quantitative NDE*, D.O. Thompson and D. Chimenti, eds. CP***, Am. Inst. Phys., 2001.

Favro, L.D., Han, Xiaoyan, Ouyang, Zhong, Sun, Gang, and Thomas, R.L., "Sonic IR Imaging of Cracks and Delaminations," *Analytical Sciences*, 17, 451-453 (2001).

Favro, L.D., Han, Xiaoyan, Ouyang, Zhong, Sun, Gang, Sui, Hua, and Thomas, R.L., "IR Imaging of Cracks Excited by an Ultrasonic Pulse," Proceedings, Thermosense XXII, SPIE Vol. 4020, pp. 182-185. 2000.

Favro, L.D., Han, Xiaoyan, Ouyang, Zhong, Sun, Gang, Sui, Hua, and Thomas, R.L., "Infrared Imaging of Defects Heated by a Sonic Pulse," *Rev. Sci. Instr*., 71, 2418, June 2000.

Favro, L.D., Han, Xiaoyan, Ouyang, Zhong, Sun, Gang, Sui, Hua, and Thomas, R.L., "Detecting Adhesion Defects Using Ultrasonic Excitation And Infrared Imaging", Proceedings, 23rd Annual Meeting of the Adhesion Society, Myrtle Beach, South Carolina, Feb. 20-23,2000. Gregory L. Anderson, ed., pp. 323-324, 2000.

Filkins, R.J., Fulton, J.P., Patton, T.C., Young, J.D., "Recent Advances and Implementations of Flexible Eddy Current Probe Technology," *Review of Progress in Quantitative NDE*, D. Thompson and D. Chimenti, eds 1998, Plenum Press, N.Y., 1997, p. 2069-2076.

Gray, J. and Tillack, G., "X-ray Imaging Methods over the Last 25 Years: New Advances and Capabilites", vol. 20A, p16, Eds. D. Thompson and D. Chimenti, American Institute of Physics, 2000.

Gray, J., "Recent Developments of an X-ray Simulation Tool, Modeling of Casting," Welding and Advanced Solidification Processes IX, 2000.

Gray, J., "Recent Developments of an X-Ray NDE Simulation Tool", Modeling of Casting, Welding and Advanced Solidification Processes, vol 9, p 36-43, P. Sahm, P. Hansen, and J. Conley, eds., Shaker-Verlag, Aachen, 2000.

Gieske, J., Roach, D., and Walkington, P., "Ultrasonic Inspection Technique for Composite Doubler/Aluminum Skin Bond Integrity for Aircraft", SPIE Nondestructive Evaluation Techniques for Aging Infrastructure and Manufacturing Conference, April 1998.

Garton, Mike, and Gray, Tim, "A Software Package for Simulating Ultrasonic Inspections in 3D CAD Geometry," *Review of Progress in QNDE*, Brunswick, Maine, July 29 – August 3, 2001.

Gao, S., and Udpa, L., "An Adaptive Morphological Filter for Defect Detection in Eddy

Current Aircraft Wheel Inspection," *Review of Progress in Quantitative Nondestructive Evaluation*, Vol. 17, D. O. Thompson and D. E. Chimenti, eds., Plenum Press, NY, 1998, pp. 1965-1972.

Han, Xiaoyan, Favro, L.D., Ahmed, Tasdiq, Ouyang, Zhong, Wang, Li, Wang, Xun, Kuo, P.K., and Thomas, R.L. "NDE of Corrosion and Disbonding on Aircraft Using Thermal Methods," *Review of Progress in Quantitative NDE*, Vol. 17, D.O. Thompson and D. Chimenti, eds., Plenum New York, (1998), pp. 449-452.

Han, Xiaoyan, Favro, L.D., Ahmed, T., Wang, Xun, and Thomas, R.L., "Delamination Depth Determinations in Composites Using Thermal Wave Imaging," *Review of Progress in Quantitative NDE*, Vol. 18, D.O. Thompson and D. Chimenti, eds., Plenum New York, (1999), pp. 593-596

Han, Xiaoyan, Favro, L.D., and Thomas, R.L., "Thermal Wave NDI of Disbonds and Corrosion," Proc. Second Joint NASA/FAA/DoD Conference on Aging Aircraft, Williamsburg, Virginia, 8/31 – 9/3/98, NASA/CP-1999-20898/Part1, pp. 265-274, ed. Charles E. Harris, Langley Research Center, Hampton, Virginia.

Han, Xiaoyan, Favro, L.D., Li, Li, Ouyang, Zhong, Sun, Gang, Thomas, R.L., and Ashbaugh, RD. Michael "Quantitative Thermal Wave Corrosion Measurements on a DC-9 Belly Skin in the Presence of Irregular Paint Thickness Variations," Review of Progress in Quantitative NDE, D.O. Thompson and D. Chimenti, eds., CP***, *Am. Inst. Phys.*, 2001.

Hsu, D.K., Peters, J.J., Fei, D., Barnard, D. J., and Dayal, V., "Imaging of Flaws in Composite Honeycomb Aircraft Structures Using Instrumented Tap Test," SPIE Conference on NDE of Aging Materials and Composites III, Newport Beach, CA, Vol. 3585, pp. 236-245, 1999.

Hsu, D.K., Peters, J.J., Barnard, D. J., Fei, D., and Dayal, V., "Imaging Flaws and Damages in Aircraft Composite Structures Using Instrumented Tap Test," ASNT Spring Conference and Research Symposium, Orlando, FL, March 22-26, 1999, pp. 139-141.

Hsu, D.K., Barnard, D. J., Peters, J.J., and Dayal, V., "Physical Basis of Tap Test as a Quantitative Imaging Tool for Composite Structures on Aircraft," *Review of Progress in Quantitative NDE*, Vol. 19, Plenum Press, New York, 2000, pp. 1857-1864.

Haldipur, P., Margetan, F.J., Yu, L., and Thompson, R.B., "Ultrasonic Attenuation Measurements in Jet-Engine Nickel Alloys", *Review of Progress in Quantitative NDE*, Vol.20, D.O. Thompson and D.E. Chimenti, eds., AIP, Melville NY, in press.

Han, Xiaoyan, Favro, Lawrence D., and Thomas, Robert L., "Sonic Infrared NDT for Crack Detection," ASNT, Portland, OR, March 19, 2002.

Han, Xiaoyan, Favro, L.D., and Thomas, R.L., "Thermosonic NDE for Aircraft Structures," UDRI, Dayton, OH, December 3, 2001.

Han, Xiaoyan, Favro, L.D., and Thomas, R.L., "Investigation of Thermosonics for Crack

Detection in Turbine Engines," DARPA Workshop, Arlington, VA, December 12, 2001.

Han, Xiaoyan, Favro, L.D., Ouyang, Zhong, and Thomas, R.L., "Thermosonics: Detecting Cracks and Adhesion Defects Using Ultrasonic Excitation and Infrared Imaging," *The Journal of Adhesion*, 76, pp. 151-162, 2001.

Howard, P.J., Copley, D.C., Gilmore, R.S., "Application of a Dynamic Threshold for C-Scan Images with Variable Noise" *Review of Progress in Quantitative NDE*, D.O. Thompson and D.E. Chimenti, eds., AIP, Melville NY, 1998.

Hsu, David K., Barnard, Daniel J., and Peters, John, J., "NDE of Repairs on Aircraft Composite Structures," Proc. of SPIE, Vol. 4336, *Nondestructive Evaluation of Materials and Composites V,* G. Y. Baaklini, E. S. Boltz, S. M. Shepard and P. J. Shull, eds., pp. 100-107, 2001.

Hsu, David K., Barnard, D.J., Peters, J.J., and Dayal, V. "Development of Nondestructive Methods for Composite Repair Inspection," *Review of Progress in Quantitative NDE*, Bellingham, WA, July 14-19, 2002.

Hsu, D.K., Barnard, D.J., Peters, J.J., Dayal, V., and Kommareddy, V., "Nondestructive Inspection of Composite and Their Repairs," 6th FAA/DoD/NASA Aging Aircraft Conference, San Francisco, CA, September 16-19, 2002.

Jensen, T. and Gray, J., "Evaluation of Large Area Amorphous Silicon Array X-ray Imager," vol. 20b, p 1860, D. Thompson and D. Chimenti, eds., *American Institute of Physics*, 2000.

Komsky, Igor N. and Achenbach, Jan D., "Characterization of Fatigue Cracks In Commuter Aircraft Using Miniature Scanning Modules", *QNDE*,1999.

Komsky, Igor N., "Characterization of Fatigue Cracks In Multilayer Aircraft Structures Using Portable Ultrasonic Modules," Proceedings, *ASIP* 2000.

Kromine, A. Fomitchov, P. Krishnaswamy, Sridhar, and Achenbach, J.D., "A Scanning Laser Source Technique for Detecting Surface-Breaking Cracks," *Materials Evaluation*, vol. 58, No. 2, pp.173-177, February 2000.

Kromine, A. Fomitchov, P. Krishnaswamy, S, and Achenbach, J.D., "Detection of Sub-surface Defects Using a Laser Based Technique," *Review of Progress in Quantitative Nondestructive Evaluation*, D.O. Thompson and D.E. Chimenti, eds., vol. 20, AIP Conf. Proc., Ames, July 16-21, 1999.

Kromine, A. Fomitchov, P. Krishnaswamy, S, and Achenbach, J.D., "Applications of Scanning Laser Source Technique for Detection of Surface-Breaking Defects," SPIE Proc. Vol. 4076, EOS/SPIE Symposium on Applied Photonics, Glasgow, Scotland, May 22-24, 2000.

Kromine, A. Fomitchov, P. Krishnaswamy, Sridhar, and Achenbach, J.D., "Scanning Laser Source Technique for Detection of Surface Breaking and Sub-Surface Cracks,"

Review of Progress in Quantitative Nondestructive Evaluation, D.O. Thompson and D.E. Chimenti, eds., vol. 19, AIP Conf. Proc. 5098, Montreal, July 26-30, 1999.

Kromine, A. Fomitchov, P. Krishnaswamy, Sridhar, and Achenbach, J.D., "Scanning Laser Source Technique and its Applications to Turbine Disk Inspection," *Review of Progress in Quantitative Nondestructive Evaluation*, D.O. Thompson and D.E. Chimenti, eds. vol. 18A, pp381-386, Plenum Press, New York, Snowbird, Utah, July 20 - 24, 1998.

Larson, B. F., "Study of the Factors Affecting the Sensitivity of Liquid Penetrant Inspections: Review of Literature Published From 1970 to 1998," FAA William J. Hughes Technical Center, Atlantic City, New Jersey, DOT/FAA/AR-01/95, January 2002.

Le, D., Roach, D.P., "Research to Improve Rotorcraft Structural Integrity, Reliability, and Safety", ISSAT International Conference on Reliability and Quality in Design, Aug. 1999.

Lavrentyev, A. I. and Rokhlin, S.I., "Ultrasonic Study of Environmental Damage Initiation and Evolution in Adhesive Joints", *Res. Nondestruct. Eval*. Vol. 10, pp. 17-41, 1998.

Lavrentyev, A.I., Baltazar A., and Rokhlin, S.I., "Ultrasonic Spectroscopy of Two Imperfect Interfaces in Contact Using Longitudinal and Shear Wave," *Rev. Progress in QNDE*, 17, 1379-1386, 1998.

Lavrentyev, A. I., Rokhlin, S.I., "Ultrasonic Spectroscopy of Imperfect Interfaces Between a Layer and Two Solids," *J. Acoust. Soc. Am.* 103, 657-664, 1998.

Li, A., Roberts, R., Margetan, F.J. and Thompson, R.B., "Model Studies of the Effect of Microstructure on Ultrasonic Signal Attenuation," *Review of Progress in QNDE, Vol. 20*.

Moore, D. G. and Fulwood, Jr. H. L., "Sensitivity Variation on Low Cycle Fatigue Cracks using Level 4/Method B Penetrant," *American Society of Nondestructive Testing, ASNT Fall Conference*, Phoenix, Arizona, October 11-15, 1999, SAND 99-2238CC, pp. 35-39.

Moore, D. G., "FAA Fluorescent Penetrant Activities – An Update," Proceedings, *American Society for Nondestructive Testing (ASNT) 1998 Fall Conference*, SAND 98-2343C, October 20, 1998, pp. 108 –110.

Margetan, F. J., Thompson, R. B., and Lerch, T. P., "An Analytical Approximation for a Common Ultrasonic Grain Noise Diffraction Integral," *Review of Progress in Quantitative Nondestructive Evaluation*, Vol. 18, D. O. Thompson and D. E. Chimenti, eds., pp. 45-52, Plenum Press, New York, NY, 1999.

Margetan, F.J., Panetta, P.D., and Thompson, R.B., "Ultrasonic Signal Attenuation in Engine Titanium Alloys," in *Review of Progress in QNDE, Vol.17B*, D.O. Thompson and D.E. Chimenti, eds., pp. 1469-1476, Plenum Press, New York, NY, 1998.

Margetan, F.J., Thompson, R.B., and Lerch, T.P. "An Analytical Approximation for a Common Ultrasonic Grain Noise Diffraction Integral," *Review of Progress in QNDE, Vol.18A*, D.O. Thompson and D.E. Chimenti, eds., p. 45, Kluwer/Plenum, New York, NY, 1999.

Margetan, F.J., Wasan, H., and Thompson, R.B., "An Experimental Study of Microstructure-Induced Ultrasonic Signal Fluctuations in Jet-Engine Titanium Alloys," *Review of Progress in QNDE, Vol.19B*, D.O. Thompson and D.E. Chimenti, eds., pp.1433-1440, AIP, Melville, NY, 2000.

Meeker, W.Q., Chan, V., Thompson, R.B., and Chiou, C.P., "A Methodology for Predicting Probability of Detection for Ultrasonic Testing," *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 20*, Thompson, D.O. and Chimenti, D.E., eds., Plenum Press, New York, NY, 2000.

Meeker, W.Q., Jeng, S.L., Chiou, C.P., and Thompson, R.B., "Improved Methodology for Inspection Reliability Assessment for Detecting Synthetic Hard Alpha Inclusions in Titanium," *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 17B*, Thompson, D.O. and Chimenti, D.E., eds., pp. 2061-2068, Plenum Press, 1998.

Minachi, A., Margetan, F.J., and Thompson, R.B., "Reconstruction of a Piston Transducer Beam using Multi-Gaussian Beams (MGB) and its Applications", *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 17A*, Thompson, D.O. and Chimenti, D.E., eds., p. 907-914. Plenum Press, 1998.

Minachi, A., Margetan, F.J., and Thompson, R.B., "Experimental Validation of the Multi-Gaussian Beam (MGB) Model," *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 19A*, Thompson, D.O. and Chimenti, D.E., eds., pp. 1041-1048, AIP, Melville NY, 2000.

Ouyang, Zhong, Favro, L.D. and Thomas, R.L., "A Practical Method for Measuring Thickness Using a Pulsed Ring Heat Source," *Analytical Science*, the international journal of the Japan Society for Analytical Chemistry.

Peters, J. J., Barnard, D. J., Hudelson, N. A., Simpson, T. S., and Hsu, D. K., "A Prototype Tap Testing Imaging System: Initial Field Test Results," *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 19*, Plenum Press, New York, 2000. pp. 2053-2059.

Peters, John J., Nielsen, Zachary A., and Hsu, David K., "Comparison of Local Stiffness of Composite Honeycomb Sandwiches Obtained by Tap Test and by Mechanical Testing", *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 20*, AIP, 2001.

Panetta, P. D., Thompson, R. B., and Margetan, F. J., "Use of Electron Backscatter Diffraction in Understanding Texture and the Mechanisms of Backscattered Noise Generation in Titanium Alloys," *Review of Progress in Quantitative Nondestructive*

Evaluation, Vol. 17A, D. O. Thompson and D. E. Chimenti, eds., pp. 89-96, Plenum Press, New York, NY, 1998.

Roach, D.P., "Bonded Composite Doubler Repairs for Aircraft Life Extension," Univ. of Alberta Advanced Engineering Materials Workshop on Fibre Composite Materials, November 1999.

Roach, D.P., Rice, T.C., and Walkington, P.D., "Development of a Biaxial Test Facility for Structural Evaluation of Aircraft Fuselage Panels," Soc. for Experimental Mechanics Spring Conference, June 1998.

Roach, D., Dorrell, L., Kollgaard, J., and Dreher, T., "Optimizing Composite Inspections", *Aerospace Engineering*, October 1999.

Roach, D., and Doetkott, G., "A Harmonized Approach to Aircraft Composite Inspection Standards", Air Transport Assoc. Nondestructive Testing Conference, October 1999.

Roach, D.P., Dorrell, L.R., "Development of Composite Honeycomb and Solid Laminate Reference Standards to Aid Aircraft Inspections," *Journal of Nondestructive Testing*, March 1999.

Roach, D.P., Dorrell, L.R., Kollgaard, J., Dreher, T., "Improving Aircraft Composite Inspections Using Optimized Reference Standards," SAE Airframe Maintenance and Repair Conference, November 1998, SAE Technical Paper 98AEMR-34.

Roach, D.P., Dorrell, L.R., "Development of a Test Facility for Structural Evaluation of Composite Rotor Hubs," Second International Workshop on Structural Health Monitoring, Stanford University, September 1999.

Roach, D.P., Walkington, P.D., Rackow, K.R., "Assessing Damage Tolerance Versus Inspection Sensitivity in Rotorcraft Components," SAE Airframe Maintenance and Repair Conference, August 1999, SAE Technical Paper 99AEMR-10.

Rokhlin, S.I., Guo, C., and Xie, B., "Ultrasonic Characterization of Environmental Degradation of Adhesive Joints," *Review of Progress in Quantitative NDE* Conference, Montreal, Canada, 1999.

Rokhlin, S. I., Baltazar, A., Xie, B., and Chen, J., "Ultrasonic Characterization of Environmental Degradation of Adhesive Bonds", in *Review of Progress Quantitative NDE*, 2000.

Rokhlin, S.I., Xie, B., Chen, J.C., and Baltazar, A., "Ultrasonic Characterization of Environmental Degradation of Adhesively Bonded Joints," Proceedings, *Second International Symposium on Adhesive Joints: Formation, Characteristics and Testing,* Newark, NJ, 2000.

Seniw, M., Fine, M., and Gray, J., "Relationship of Defect Size and Location to Fatigue Failure in Al Alloy A356 Cast Specimens," Proceedings, *Paul Paris Symposium*, 1998.

Shull, K.R., Brinson, L.C., Nunalee, F.N., Bai, T., Mason, T.O., and Carr, S.H., "Aging Characterization of Polymeric Insulation in Aircraft Wiring Via Impedance Spectroscopy," Proceedings, *5th Joint Conference on Aging Aircraft*, Orlando, Florida, 10-13 September 2001.

Sun, G., Wang, Xun, Feng, Z.J., Jin, Huijia, Sui, Hau, Ouyang, Zhong, Han, Xiaoyan, Favro, L.D., and Thomas, R.L., "Imaging and Quantitative Measurement of Corrosion in Painted Automotive and Aircraft Structures," Review of Progress in Quantitative NDE, D.O. Thompson and D. Chimenti, eds., CP509, Am. Inst. Phys., pp. 603-607, 2000.

Thomas, R.L., Han, Xiaoyan, and Favro, L.D., "Thermal Wave Imaging of Aircraft for Evaluation of Disbonding and Corrosion", Proceedings, *7th European Conference on Non-Destructive Testing*, Copenhagen, Denmark, May 26-29, 1998, pp. 126-130.

Thomas, R.L., Favro, L.D., Han, Xiaoyan, and Ouyang, Zhong, "Thermal Methods Used in Composite Inspection," *Comprehensive Composite Materials, Vol. 5*, L. Carlsson, R.L. Crane and R. Davidson, eds., Pergamon/Elsevier Science, Oxford, 2000.

Tillack, G., Artemiev, V., and Gray, J., "The Effects of Scattered Radiation in X-ray Techniques- Experimental and Theoretical Considerations," *Review of Progress in Quantitative NDE, vol. 18A*, p631, D. Thompson and D. Chimenti, eds., Plenum Press, 1999.

Thompson, R. B., "Overview of the ETC POD Methodology," *Review of Progress in Quantitative Nondestructive Evaluation, Vol. 18*, D. O. Thompson and D. E. Chimenti, eds., pp. 2295-2304, Plenum Press, New York, NY, 1999.

Thompson, R.B., Panetta P., and Margetan, F.J., "Relationship of the Ultrasonic Backscattering Coefficient of Titanium Alloys to Microstructure," *Materials and Processes Affordability: Keys to the Future*, H. S. Kliger, B. J. Rasmussen, L. A. Pilato, and T. B. Tolle, eds., pp.1448-1457, SAMPE, Covina, CA, 1998.

Thompson, R.B., Margetan, F.J., Yalda, I., Chiou, C.P., and Panetta, P., "Coupling Microstructure Outputs of Process Models to Ultrasonic Inspectibility," in *Review of Progress in Quantitative Nondestructive Evaluation, Vol.17B*, D.O. Thompson and D.E. Chimenti, eds., pp. 1847-1453, Plenum, New York, 1998.

Udpa, L., Shih, W.C.L., and Fitzpatrick, G.F., "Improved Magneto-Optic Sensors for Detection of Subsurface Cracks and Corrosion in Aging Aircraft," 5th Joint NASA/FAA/DoD Conference on Aging Aircraft, September 10-13, 2001, Orlando, Florida.

Wendt, S., Gray, J., and Beckman, S., "Energy Dispersive Measurements of Anisotropic Diffraction Mottling Effects," *Review of Progress in Quantitative Nondestructive Evaluation, vol. 20a*, D. Thompson and D. Chimenti, eds., p514, *American Institute of Physics*, 2000.

Wenner and Spencer, "NDI Capability Characterization and Methodology Development

for Aircraft Inspections," AANC Report, 2000.

Wang, L., Rokhlin, S. I., and Baltazar, A., "Determination of Bulk and Interfacial Properties of a Bonding Layer from Normal and Oblique Reflection Spectra", *Review of Progress in Quantitative NDE* Conference, Montreal, Canada, 1999.

Xuan, L., Zeng, Z., Shanker, B., and Udpa, L., "Development of a Meshless Finite Element Model for NDE Applications," ACES Conference, Monterey, California, March 2002.

Xuan, L, Shanker, B, Udpa, L., Shih, W., and Fitzpatrick, G., "Finite-Element Modeling for Magneto-Optic Imaging Applications," *Review of Progress in Quantitative NDE*, Iowa State Center, Iowa State University, Ames, IA, July 16-21, 2000.

Xie, Q., Lavrentyev, A.I., and Rokhlin, S.I., "Ultrasonic Characterization of Thin Plate Bonding," *Review of Progress in Quantitative Nondestructive Evaluation*, *vol. 17*, D.O. Thompson and D.E. Chimenti, eds., pp. 1379-1386, 1998.

Yalda, I., Margetan, F.J., and Thompson, R.B., "Use of Rician Distributions to Predict Distributions of Ultrasonic Flaw Signals in the Presence of Backscattered Noise," *Review of Progress in Quantitative Nondestructive Evaluation*, *vol. 17A*, D.O. Thompson and D.E. Chimenti, eds., pp. 105-111, Plenum, New York, 1998.

Yu, L., Yanming. G., Margetan, F.J. and Thompson, R.B., "Effect of Microstructure on Ultrasonic Attenuation Measurements Using Focused Transducers," *Review of Progress in Quantitative Nondestructive Evaluation*, *vol. 20*, D.O. Thompson and D.E. Chimenti, eds., AIP, Melville NY, in press.

Zawadzkas, M. A. and Moore, D. G., "FAA Fluorescent Penetrant Laboratory Inspections Technical Report," Fourth Annual Symposium, Summer Technical Student Internship Program, Albuquerque, New Mexico, July 30, 1999.

Information Dissemination

A Presentation was made during a meeting at Wichita State University to restart the project on 11/21/01. Present at the meeting were the investigators from WSU, Raytheon Aircraft, and representatives from the FAA. This presentation was distributed to industry and FAA contacts for the project.

A Presentation on the project status was made at the AACE bi-annual review at Wichita State University on 02/21/02. This presentation was distributed to industry and FAA contacts for the project. [aace2002AFCS.doc]

ARINC ADN Working Group meeting at Orlando, FL, Feb. 12-15, 2002.
Discussion with the members of the working group about our research projects, the network structure suitable for deterministic operations, and the safety and certification concerns.

FAA Casting Workshop, November 6th, at Northwestern.

"Multi-Element Adjustable Transducer Arrays for Ultrasonic Scanning of Aging Aircraft", in Proceedings of SPIE, 2002.

Paper submitted to 6th Joint FAA/DoD/NASA Aging Aircraft Conference: "Improved Magneto-Optic Sensors for Detection of Subsurface Cracks and Corrosion in Aging Aircraft."

Abstract submitted, "Engineering Assessment of Fluorescent Penetrant Inspection: New Research Efforts," Lisa Brasche and Alfred L. Broz, to the 6th FAA/NASA/DOD Aging Aircraft Conference.

Centers of Excellence

General Aviation

Established June 2001

Embry-Riddle Aeronautical University
Florida Agricultural and Mechanical University
University of Alaska
University of North Dakota
Wichita State University

The Federal Aviation Administration (FAA) established a Center of Excellence (COE) in the technology area of general aviation (GA) in 2001. General aviation, commonly known as GA, is defined as all aviation other than military and commercial airlines. GA aircraft range from small, single-engine planes to mid-size turboprops to the larger turbofans capable of intercontinental non-stop flying. General aviation supports business and recreation, and serves a diversity of needs from emergency medical evacuations to border patrols, fire fighting, state governments, universities, companies and individuals.

GA research areas of concern are maintenance, inspection and repair, manufacturing, crashworthiness, propulsion and fuel systems safety technologies, landing gear systems performance and safety, advanced materials, airports, and training.

The FAA is awarding 50-50 matching grants through a cooperative agreement and single-source contracts. The contracts will consist of both cost-sharing and 100% funded indefinite delivery indefinite quantity type. The FAA has committed to fund the Center at $300 thousand per year during the first 3 years. During FY'01, the FAA awarded $1.3M for 9 tasks in matching grants.

Sponsoring Organization: Airport and Aircraft Safety R&D Division

FAA-GA Program Manager: Peter Sparacino (609-485-5430)
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Prof. Paul Lindseth, co-director, UND, 701-777-2917
Prof. Lutfi RAAD, co-director, UAF, 907-474-7497
Prof. Leonard Kirk, co-director, UAA, 907-264-7436
Prof. John Tomblin, co-director, WSU, 316-978-5234
Prof. Venkitaswamy Raju, co-director, FAMU, 850-599-3506

Core Team Partners: See attached list

Center of Excellence in General Aviation
CGAR Organization

COE Industrial Partners	COE Core Team	COE Advisory Group
Aero Shell	Embry-Riddle Aeronautical University – Daytona Beach and Prescott	Aircraft Owners and Pilot's Association (AOPA)
Aircraft Welding Works	Florida Agriculture and Mechanical University	Experimental Aircraft Association (EAA)
Alaska Airmen's Association	University of Alaska – Anchorage and Fairbanks	National Business Aircraft Association (NBAA)
Alaskan Aviation Safety Foundation	University of North Dakota	General Aviation Manufacturing Association (GAMA)
Aviation Management Associates	Wichita State University	Small Aircraft Manufacturing Association (SAMA)
Bombardier Aerospace		
Cessna Aircraft Corporation		
Cirrus		
Frasca		
Goodrich		
HandySoft Corporation		
Hartzell		
Jeppesen		
Lancair		
Raytheon Aircraft Company		
SMA		
The Alaska Science and Technology Foundation		
The Boeing Company		
Vector Training Systems		

Development of Analytical Methods to Predict crash impact Responses of General Aviation Aircraft Seat/Occupant/Restraint System

The goal of this project is to come up with procedures and capabilities for development of analytical methods and models to predict the dynamic response of GA aircraft structures, seat/occupant/restraint systems and interior structural members to crash impacts.

Investigator: Dr. Hamid Lankarani, WSU

In-flight Load Data Collection and Analysis Project

Federal Aviation Regulations require that structures critical to the safe operation of an aircraft must not fail within their expected lifetimes due to damage caused by the repeated loads typical to its operations. This requirement generates the need for evaluating the fatigue life of critical aircraft structures. Two of these are the wings and the empennage structure. Most commonly, the fatigue life is determined using the Palmgren-Miner linear cumulative damage theory. To calculate the fatigue life using this method, one most know the loading history or the loading spectra of the aircraft. There is information on flight loads. i.e., normal acceleration near aircraft center of gravity, for general aviation aircraft that can be used to determine the fatigue life of airplane wings. However, there is no comparable information for empennage loads, and together with the 1999 suspected structural fatigue in-flight separation of the right wing of a T-34, there is a renewed urgency to better understand in-flight loads.

Investigator: Dr. David Kim, ERAU - Daytona

Evaluation of Gravel Runway Surface Conditions and Their Effects on Aircraft Performance During Winter Operations

Following the fatal aircraft accident in Dryden, Ontario, in 1989, the Dryden Commission of Inquiry investigated the disaster and recommended the need to establish a technically accurate means of defining surface conditions of runways and their effect on aircraft safety. In response to this, Transport Canada (TC) and the U.S. National Aeronautics and Space Administration (NASA) developed a 5-year initiative study to investigate the winter runway friction measurements. The initiative was supported by a number of national and international organizations that resulted in the formation of the Joint Winter Runway Friction Measurement Program (JWRFMP) in January 1996. As a result, a number of studies administered by JWRFMP between 1996 and 1999 were undertaken to determine the winter friction characteristics for runways and establish runway surface parameters that will enhance aircraft operation safety during landing and takeoff. Over 13 ground vehicles and 5 instrumented aircraft types (Falcon 20, B-757, B-737, and B-727) were used in these studies.

General aviation needs and facilities are markedly different than those required for commercial and passenger aircraft. GA is the most predominant air transportation in Alaska. The state has 1112 airports, seaplane bases, and other aircraft landing sites for GA aircraft. There are 286 public-use airports in the state. They stretch from Barrow on

the north cost, 700 miles south to Anchorage on the Cook Inlet. They also extend from Wales in the west, eastward over 750 miles to Northway near the border of the Yukon Territory in Canada. There is now one public use airport for every 2000 square miles in Alaska. The majority of these are rural airstrips. A typical airstrip is 3000 feet long, 75 feet wide, and is built from compacted gravel.

During the 9-year period from 1986 to 1994, the relative frequency of Alaska accidents per 100,000 flight hours ranged from 1.4 to 3.2 times higher than the rest of the United States (6). In 1995, the National Transportation Safety Board (NTSB) indicated that while progress has been made over the last 15 years in reducing the number of accidents, there are still major areas of concern that must be addressed. Specifically, Alaska's aviation safety record is consistently the worst among the 50 states. The major concerns of the NTSB concentrate on the accuracy, availability and consistency of runway and weather information at remote airstrips.

Breakup in the spring poses special difficulties in terms of GA operations. Cyclic freeze-thaw temperatures create glare ice that could be wet, slippery, or both. The presence of ruts, slush, and potholes could also compound the adverse effects of glare ice. Poor runway surface conditions coupled with unfavorable winds create an unsafe environment during aircraft landing. Occurrences of aircraft sliding at the end of the runway are not uncommon. Sand and gravel are often used to neutralize the effects of glare ice. Other methods, such as driving up and down the runway with a tracked bulldozer that puts cuts in the ice perpendicular to the runway centerline are often used to roughen the surface. GA accidents occurred at 6 times the frequency of commercial aviation accidents. Most accidents occurred during landing, and those related to poor runway conditions could reach 51 percent of the total number of GA accidents. GA pilots are, therefore, a prime audience that should benefit from improved runway and weather reporting conditions.

Although a number of studies have been recently conducted to investigate the winter traction performance of vehicles on paved asphalt surfaces, no such studies have been performed on gravel surfaces during freeze-thaw. Moreover, no data are available on the influence of gravel runway surface conditions during the critical spring breakup period on aircraft safety performance. These data constitute an important parameter for runway condition reporting necessary for safe GA operations.

Investigator: Dr. Lutfi Raad, UAF

Taxiway Centerline Deviation Study

A taxiway centerline deviation study is being conducted to research the deviation from centerline of aircraft and the effect this may have to taxiway standards in the area of width and separation and existing taxiway networks. The study will include equipment provided by the FAA and already installed at Anchorage International Airport. The scope of work will include the following: (1) weekly checks for laser alignment, (2) bi-weekly data downloads, (3) data reduction, (4) bi-weekly data transfer, (5) maintain a journal of activity with photos, (6) development of software routines to sort data by various aircraft type, and (7) other work as mutually agreed.

Investigator: Dr. Leonard Kirk, UAA

Terminal Operations Safety Research Project-Landing and Holding Short

Federal Aviation Regulations require that structures critical to the safe operation of an aircraft must not fail within their expected lifetimes due to damage caused by the repeated loads typical to its operations. This requirement generates the need for evaluating the fatigue life of critical aircraft structures. Two of these are the wings and the empennage structure. Embry-Riddle is proposing that it use graduate students enrolled in the MSSS program to collect and assist in analyzing data available at Prescott's Earnest A. Love Field (PRC) as a a sub-set of the LAHSO portion of the Terminal operations Safety project. Love Field is primarily a general aviation airport, and has over 350,000 operations a year, making it one of the busiest small airports in the country, largely due to the large number of operations of the University with over 900 active flight students in its Aeronautical Science program at any given time.

Investigator: Dr. Randall Johnson, ERAU – Prescott

Aviation Safety Education and Research at Florida A&M University

Florida A&M University (FAMU) proposes to develop an academic program and research infrastructure aimed at supporting the efforts of the Federal Aviation Administration (FAA) in improving aviation safety. As a member of FAA's Center of Excellence for General Aviation Research (CEGAR), FAMU proposes to help aviation industry by producing highly qualified minority graduates, and undertaking aviation related research. The proposal includes establishing a bachelor of science degree in aviation technology, creating an option in aviation management and safety in the master's degree program, and enhancing the faculty and laboratory infrastructure. The goal is to produce 12 graduates with aviation background in 2002 and 50 graduates with a degree in aviation technology by 2008. Partnership with high schools, community colleges, FAA, members of CEGAR and aviation industry will form the basis upon which to build curricula, recruit students and undertake research. This proposal includes 50 scholarships to attract minority students to programs in aviation in 2001-2002. It also includes plans to target 40 high schools in the east from Atlantic City to Miami and a dozen community colleges in Florida. The proposed academic and research infrastructure at FAMU will enable the university to promote and contribute to workforce diversity in aviation industry.

Investigator: Dr. V. Raju, FAMU

Security Plan for General Aviation

The purpose of this project is to develop a methodology to create a plan for improving general aviation security in the United States. The plan will include: (1) a survey of the general aviation security landscape, (2) a thorough review of all applicable literature, (3) a study of the security concerns of the professional associations that deal with general aviation, (4) discovery of security technology applicable to general aviation, (5) a discussion of possible short-term, mid-term, and long-term security strategies for general aviation, (6) a matrix of recommendations that will address policy and procedure, regulatory and certification issues, technology applications, phased implementation, and funding issues.

Investigator: Dr. Tim Brady, ERAU - Daytona

Establish a Special Emphasis Outreach Program at the University of Alaska

The University of Alaska Anchorage (UAA), Aviation Technology Division, is a land-grant institution, having 16,000 students, and produces more than 2,000 graduates annually. The university's baccalaureate academic programs include, among others, arts and sciences, engineering, business, nursing, and aviation technology. The university has a long history of working with industry and government in developing and promoting diversity in the technical and managerial workforce of the State of Alaska. UAA would like to expand its role to include aviation industry. This proposal recommends implementation of a program in Aviation Education at the University of Alaska Anchorage that significantly enhances the human resource base in aviation by enhancing diversity.

Investigator: Dr. Leonard Kirk, UAA

CGAR Strategic Plan for Self Sufficiency

The purpose of this grant proposal is to set forth a comprehensive strategic plan, addressing the overriding goal of the CGAR in developing synergistic relationships among team members to further innovation in general aviation research activities. Furthermore, it is intended to develop a self sufficiency plan that will enable the member institutions to cultivate a successful collaborative relationships with the public and private sectors.

Investigator: Dr. Abe Harraf, ERAU – Daytona

Measurements of Icing Conditions in Western Atlantic Stratocumulusi

This project will help determine whether stratocumulus clouds caused by cold air outbreaks over the Western Atlantic Ocean provide suitable test conditions for aircraft certification requirements. The University of North Dakota's (UND) Citation aircraft will be used to collect representative microphysical data samples that will be analyzed to characterize the distribution of supercooled liquid water in these clouds.

Investigator: Dr. Michael Poellot, UND

Ethanol as a fuel for General Aviation

Ethanol-based fuels provide an attractive alternative to traditional aviation gasoline. Ethanol tends to burn cleaner and cooler as well as provide greater resistance to detonation. As tetraethyl lead becomes harder to acquire (due to lack of demand and availability), it becomes imperative to develop high-performance alternatives to 100LL aviation gasoline. This proposal outlines a plan to perform basic, introductory testing of an ethanol-based fuel known as Aviation Grade Ethanol 85 (AGE-85) to determine its suitability as an aviation fuel for piston engines.

This project builds on 5 years of work performed by South Dakota State University and the University of North Dakota, along with a team of collaborators, that has resulted in

the development of AGE-85. AGE-85 is a blend of approximately 85% undenatured ethanol, 14% pentane isomerate, and 1% biodiesel. By blending these three components, the desirable properties of aviation gasoline are maintained while, at the same time, the advantages of an ethanol-based fuel are realized.

Three areas of investigation will be pursued. (1) a study of the fuel properties as related to the blending constituents and proportions, (2) an analysis of AGE-85 in aircraft engines will be undertaken with special emphasis on combustion pressures, detonation, and fuel efficiency, and (3) includes those analyses related to airframes including material compatibility, fuel system compatibility, flight operational procedures and flight safety using AGE-85 and blends with 100LL.

Investigator: Dr. Paul Lindseth, UND

Centers of Excellence

Aircraft Noise and Aviation Emissions Mitigation

Established September 2003

Boise State University

Florida International University

Georgia Institute of Technology

Massachusetts Institute of Technology

Pennsylvania State University

Purdue University

Stanford University

University of Central Florida

University of Missouri – Rolla

Environmental issues are likely to impose a limit on airport capacity in the 21st century. The U.S. Federal investment in local noise mitigation through the Airport Improvement Program (AIP) and Passenger Facilities Charge (PFC) has increased fivefold since the early 1980s. Local actions, such as curfews and other restrictions, by airport authorities around the world have grown tenfold in the same time period. These statistics suggest a need to determine if we are using the right metrics to assess the impact of aircraft noise and the efficacy of local mitigation investments. The uncertainties surrounding the atmospheric and health effects of aviation emissions complicate adopting effective mitigating measures and lengthen airport environmental assessments. Specifically, the impact of particulate matter and hazardous air pollutants remains unknown because of the lack of both experimental data and reliable models.

To address the noise and emissions issues discussed above, the FAA has created a new Air Transportation Center of Excellence (COE) for Aircraft Noise and Aviation Emissions Mitigation, dubbed PARTNER – Partnership for AiR Transportation Noise and Emissions Reduction. The group will conduct basic research and engineering development to identify and help implement solutions for existing and expected noise and emissions-related problems. The knowledge and capability gained from this research will provide critical information to government and industry decision-makers to tackle environmental impacts. The Center will also help nurture the next-generation workforce to meet the continuing challenges of aviation environmental issues. NASA is a cosponsor of the Center and the FAA expects to sign an agreement with Transport Canada to also cosponsor the PARTNER.

The FAA is awarding 50-50 matching grants through a cooperative agreement and

single-source contracts. The contracts will consist of both cost-sharing and 100% funded indefinite delivery indefinite quantity type. The FAA has committed to fund the Center at a minimum $600 thousand per year during the first 3 years. During FY'03, the FAA awarded $1.450M for 8 tasks in matching grants. During FY'04, the FAA expects to award $1,185M for 8 tasks. During FY'04, NASA expects to contribute $1,000M to projects complimentary to the tasks funded by FAA and $500 thousand to support a task on supersonic transport environmental issues. Transport Canada plans to contribute $150 thousand in FY'04 to emissions research tasks.

Sponsoring Organization: FAA Office of Environment and Energy with NASA and Transport Canada

FAA-NE Program Manager: Lourdes Maurice (202-493-4293)

COE Core Team – Points of Contact
Professor John-Paul Clarke, GIT
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Professor Philip D. Whitefield, UMR, 573-341-4340

Core Team Partners: See attached list

Center of Excellence in Noise and Emissions Reduction PARTNER Organization

COE Industrial Partners	COE Core Team	COE Advisory Board*
American Institute of Aeronautics and Astronautics	Boise State University	Airports Council International
Aerodyne Research, Inc.	Florida International University	FAA
Bell Helicopter Textron	Massachusetts Institute of Technology	NASA
Boeing	Pennsylvania State University	National Organization for a Sound-Controlled Environment (N.O.I.S.E.)
Delta Air Lines	Purdue University	O'Hare Noise Compatibility Commission
General Electric Aircraft Engines	Stanford University	Transport Canada
Gulfstream Aerospace	University of Central Florida	Volpe National Transportation Systems Center
Lockheed-Martin Aeronautics Company	University of Missouri-Rolla	
Logistics Management Institute	Georgia Institute of Technology	
Massachusetts Port Authority		
Metron Aviation		
Metropolitan Washington Airports Authority		
Pratt & Whitney		
Raisbeck Engineering		
Rannoch Corporation		
Regional Airport Authority of Louisville and Jefferson County		
Rolls-Royce		
Sikorsky Aircraft		
United Parcel Service		
Wyle Laboratories		

* All Industrial Partners and Core Members are also members of the PARTNER Advisory Board

On-Going Projects

Low Frequency Noise Study

Pennsylvania State University, Purdue University, University of Central Florida, Boeing, and Wyle Laboratories will study low frequency noise produced by aircraft around airports. Low frequency noise of enough energy can excite buildings to vibrate. The vibration can induce rattle contributing both to the perception and annoyance of the noise source. By measuring the sound, vibration, and community impact (through subjective interviews) under various meteorological conditions, the research should lead to new analytical models and innovative sound insulation techniques.

Investigator: Kathy Hodgdon, PSU
Co-Investigators: Dr. Patricia Davies, Purdue, Professor Roger Wayson, UCF

Measurements, Metrics and Health Effects of Noise

Pennsylvania State University, Purdue University, Boeing, General Electric, Pratt & Whitney, Rolls-Royce, and Wyle Laboratories will undertake a noise metrics, measurements, and health effects research project. The objectives of this project are to develop useful metrics to evaluate the impact of airport and other noise sources on a community and to understand the relationship among noise annoyance, physiological responses, cognitive performance, and sleep quality.

Investigator: Dr. Patricia Davies, Purdue
Co-Investigators: Kathy Hodgdon, PSU

Valuation and Tradeoffs of Policy Options

Massachusetts Institute of Technology, Stanford, Boeing, Delta Air Lines, General Electric, Logistics Management Institute, Pratt & Whitney, Rannoch Corp., Rolls-Royce, and Wyle Laboratories will evaluate the trade-offs of policy choices. The overall objective of this project is to develop and use system-level performance and cost estimation tools to evaluate interactions between technology, operations, policy, and environmental impact. Estimates of the direct costs, opportunity costs and external costs of noise, local air quality, and climate change will form the basis of these assessments.

The FAA Reauthorization Bill (H.R. 2115) that was recently signed into law includes a provision for a study of ways to reduce aircraft noise and emissions. Also under this task, PARTNER will lead this study and is expected to help develop a shared vision of national goals for aviation and the environment and to make recommendations for a sustainable plan of action to achieve these goals.

Investigator: Professor Ian Waitz, MIT
Co-Investigator: Professor Ilan Kroo, Stanford

Continuous Descent Approach at Louisville International Airport

Massachusetts Institute of Technology, Boeing, Delta Air Lines, Regional Airport Authority of Louisville, and United Parcel Service will study Continuous Descent Approach Procedures (CDA). This project builds on results from a recent CDA study at Louisville International Airport, which showed the average noise decrease during the CDA procedure was between three and six decibels. A person of average hearing would notice a three-decibel difference and would recognize a 10-decibel decrease as being half as loud. Also, the CDA procedure is more fuel-efficient. The objective of the COE CDA

effort is to design a noise abatement approach procedure that will serve as a model for other airports in the rest of the nation, and perhaps, the world.

Investigator: Professor John Paul Clarke, MIT

Land Use Management and Airport Controls

Florida International University, Purdue University, Delta Air Lines, Metropolitan Washington Airports Authority, Regional Airport Authority of Louisville, and Wyle Laboratories will study land use practices and airport controls. The objectives are to better understand the effectiveness of local actions to reduce the impact of aircraft noise and to use this information to improve land use in and around airports.

Investigator: Dr. Gary Eiff, Purdue
Co-Investigator: Dr. John Laffitte, FIU

Sonic Boom Mitigation

Pennsylvania State University, Purdue University, Stanford University, Boeing, Gulfstream, Lockheed-Martin, and Wyle Laboratories will study supersonic transport sonic boom and annoyance. The objectives of this study are to assess applicability of existing noise metrics to sonic boom and to determine annoyance of low boom waveforms. The findings will help inform future decision-making on supersonic flight over land. The research could lead to developing new regulations for supersonic aircraft in the United States and worldwide.

Investigator: Dr. Vic Sparrow, PSU
Co-Investigators: Professor Ilan Kroo, Stanford, Kathy Hodgdon, PSU, and Dr. Patricia Davies, Purdue

Measurements, Metrics, and Health Effects of Emissions

Boise State University, Florida International University, Massachusetts Institute of Technology, Florida International University, University of Central Florida, University of Missouri-Rolla, Aerodyne, Boeing, General Electric, Pratt & Whitney, and Rolls-Royce will characterize the emissions (both small particles and condensable gaseous species) from aircraft and airports through measurements, understanding and modeling the microphysical processes associated with particle and other pollutant formation, and determining appropriate indices to quantify the health effects of emissions. One of the first activities is to collect particulate matter data using Light Detection and Ranging (LIDAR) providing data to improve the Emissions Dispersion Modeling System (EDMS) analytical model widely used by airports to conduct environmental assessments.

Investigator: Professor Joe Hartman, BSU
Co-Investigators: Professor Roger Wayson, UCF, Professor Phil Whitefield, UMR, Professor Karen Polenske, MIT, Dr. Davied Roelant, FIU, and Professor Jim McGlothlin, Purdue

Atmospheric Impacts of Aviation

Stanford University, Massachusetts Institute of Technology and Aerodyne will assess the state of knowledge on the atmospheric impact of commercial and other aircraft operating at cruise altitudes since the Intergovernmental Panel on Climate Change (IPCC) report, "Aviation and the Global Atmosphere," published in 1999. This effort will help guide future COE activities on atmospheric effects of aviation.

Investigator: Professor Sanjiva Lele, Stanford
Co-Investigator: Professor Ian Waits, MIT

Community Outreach

Pennsylvania State University, Purdue University, Florida International University and Wyle Laboratories will seek to provide an internet capability to educate and inform the public about aviation and the environment; thus enabling the community to actively participate in any public process

Investigator: Kathy Hodgdon, PSU
Co-Investigators: Professor Gary Eiff, Purdue, and Dr. David Roelant, FIU.